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INTO THE 21ST CENTURY

SMALL ARMS

D F Allsop & M A Toomey

LAND WARFARE

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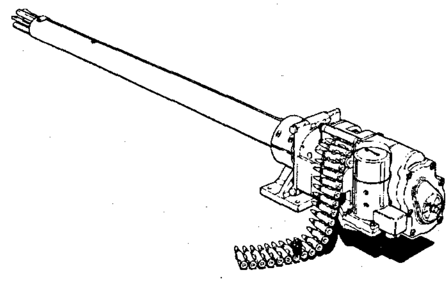

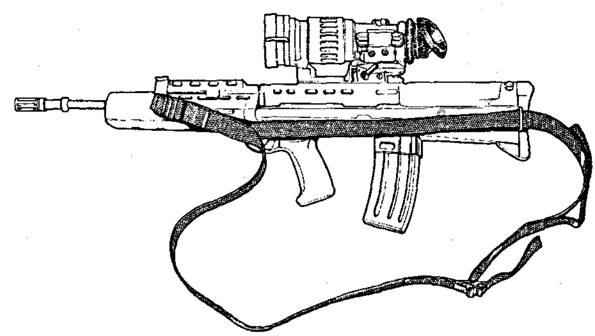

SMALL ARMS
General Design

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Ritana
BOOKS

This Indian edition published 2004 by
Ritana Books
81, Defence Colony, Flyover Market,
New Delhi-110024
Tel. : 24617278
Fax : 24636063
Email : ritana@vsnl.com
website : www.ritanabooks.com

By arrangement with
Brassey's

A member of the Chrysalis Books Group Plc

Library of Congress Cataloging in Publication Data available

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN 1 85753 250 3 Hardcover - UK Edition.

ISBN - 81-85250-35-9 Hardcover - Indian Edition

Published by Rock Furtado for Ritana Books
and Printed at Print Perfect, New Delhi

Preface

THE SERIES

This series of books is written for those who wish to improve their knowledge of military weapons and equipment. It is equally relevant to professional soldiers, those involved in developing and producing military weapons or indeed anyone interested in the art of modern warfare.

All the texts are written in a way which assumes no mathematical knowledge and no more technical depth than would be gleaned from school-days. It is intended that the books should be of particular interest to army officers who are studying for promotion examinations, furthering their knowledge at specialist arms schools or attending command and staff schools.

The authors of the books are, or have been, military or civilian members of the staff of the Royal Military College of Science, Shrivenham, which comprises a unique blend of academic and military experts. They are not only leaders in the technology of their subjects, but are aware of what the military practitioner needs to know. It is difficult to imagine any group of persons more fitted to write about the application of technology to the battlefield.

VOLUME 6

This book provides a solid grounding in the application, design and methods of operation of this very important class of weapons. The scope and application of military small arms as used by modern military powers is discussed and their performance and limitations are explained. The methods of achieving automatic operation, both by self power and external power, are explained and the advantages and disadvantages of each type of operating method are given. Small arms ammunition is covered, giving design and construction details. The individual components of small arms, such as breeches, locking mechanisms, barrels, triggers and firing mechanisms, ammunition feed and sights are described and the advantages and disadvantages of different approaches to component design are discussed. Future developments in the search for improved weapon performance and the direction these developments are likely to take are also discussed in detail.

Geoffrey Lee, Shrivenham

Acknowledgements

The authors greatly appreciate the generosity of DDOR (LtWpns&Sim) and the ATSA Directorate of Engineering in allowing them to use some of the line drawings from AESP 1000-A-002-013.

Thanks are also due to all those who taught this subject at The Royal Military College of Science in the past for the accumulated knowledge to be found in this book.

Disclaimer

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1. The Military Requirement

Definition of Small Arms

There are many slightly different definitions of Small Arms. In general most talk of man or crew portable, relatively flat trajectory, largely shoulder controlled weapons, in calibres up to 12.7mm, used primarily to incapacitate or suppress the enemy with bullets or fragments. Cannons take over after 12.7mm and can go up to 50mm.

Fundamental Reasons for Small Arms

While the weapon has received the notoriety, often of mythical or romantic legend, it is the ammunition that provides the results. A small arm only exists to fire the projectile. The primary object of military small arms is to inflict control over a person, either by death, incapacitation or suppression. Both the user and designer must be careful to keep this fundamental fact in mind and not be seduced into trying to include other capabilities such as taking on aircraft, helicopters or light skinned vehicles. If it so happens that a weapon, after development, is useful against such targets, then it is an added bonus.

Justification

The small proportion of total battlefield casualties caused directly by small arms, varying from 15 to 30% depending on the predominance of infantry engaged in the battle, is often used as a reason for getting rid of them. However this does not take into account the vital need to take and hold ground, which can only be achieved by the infantry. A small arm is by far the best weapon for these tasks. Indeed all military persons have a small arm issued for their personal protection and it is a great boost to their morale. It is a matter of historical fact that, in a great many situations, the small arm was never pointed at a seen target, but was used as a very cost-effective way of keeping the enemies' heads down. Another good reason for small arms is the need to use the minimum of force, applied accurately, in operations other than all out war. Unfortunately the choice of calibre does not always follow the indications of the technical factors, but also takes into account political considerations.

Small Arms as a System

All too frequently the development and introduction of small arms into service has been piecemeal. Small arms must be looked upon as a system where all the

items making up that system come together. Indeed there is much more that should be considered, for the person is part of the system and there are many other items that must not only be compatible, but also integrated in order to make him an efficient fighting force. Helmet, gas mask, headsets, ear defenders, vision goggles, combat body armour, NBC suit and there are many other items go to make up the rifleman today. However the small arm as a system includes such items as:

- Ammunition
- Weapon
- Bayonet
- Grenade projector
- Sight
- Sling
- Blank firing attachment
- Cleaning kit
- Spare parts
- Armourer's tools and gauges
- AESPs (Army Equipment Support Publications)
- Indoor simulator
- Tactical trainer
- Weapon training and user pamphlets

This may seem a long list, but all these items are necessary. Ammunition is the greatest cost over ten years and training areas are being squeezed, yet danger areas are becoming larger. Training casualties are unacceptable and, even when a nation goes to war, people find casualties distasteful. All these factors point to the need for the inclusion of an indoor simulator and tactical trainer and are fundamental today and in the future.

Family of Small Arms

If care is not taken, the number of weapons proliferates, so that there is one for every situation. This is obviously unacceptable, especially in times of financial stringency. However it is equally obvious that one cannot fulfil all requirements with one or two weapons only. In an endeavour to specify the smallest family of weapons for use beyond the year 2000, NATO Panel III set down the following requirements.

- Personal Defence Weapon (PDW).
- An Individual Combat Weapon (ICW).
- A Medium Support Weapon (MSW).

It has proved impossible to meet these ideals fully. In both the categories of the PDW and the MSW, it is expected that there will need to be two weapons in order to satisfy the requirements envisaged. Furthermore there is the

probability that a Sniper Rifle and possibly a Combat Shotgun should be added to the list.

Tactical Considerations

Our own and the enemy's present and future tactics shape the military requirement. This is particularly true where a country has a huge army, most of whom are conscripts, leading to cheap, simple and short range weapons such as Russia and China have adopted. More and more nations are coming round to the traditional British philosophy of using aimed shots, rather than just a large volume of fire. Even the Russians appear, with their new Nikonov rifle design, to have moved towards the idea of aimed fire. Advances in technology equally have had their effect. Winning the firefight is mainly about who can get the heaviest weight of effective fire down onto the opposition. This leads to choosing the smallest and lightest round that will achieve the required effect. No weapon has ever fully satisfied the military requirement and therefore the tactics have had to be amended in order to accentuate the best points and overcome any shortcomings.

Logistics

Resupply of smaller and lighter ammunition makes sense in operations. Ideally the weapon can be made a more acceptable weight, however lighter weapons tend to be less rugged, have smaller working parts that are easily broken or lost and produce unacceptable recoil.

Required Characteristics

In order to fulfil all requirements, any new small arm would need:

- Decisive and violent target effects.
- Accuracy in all weathers, day and night on both fleeting and defilade targets.
- Increased target effect from fewer rounds fired.
- Lightweight weapons and ammunition.
- Effectiveness at full range.
- Simplicity, ruggedness and affordability.

Essential Data

Before a requirement or design can be started, there are some fundamental questions that must be answered. This is true whether the weapon in question be anything from a hand grenade to an artillery piece.

What is the *Target*
How is it *Protected*

What *Effect* is required
At what *Range*

The Target

Size

The overall area of an average man standing, viewed from the front, is $0.5m^2$. Of this area, the head, neck, thorax and abdomen are the places most likely to suffer an incapacitating wound. This accounts for 45% of the whole. For instantaneous incapacitation the area is even smaller, some 15% of the whole, consisting of the head and the upper spine. Part of the Collaborative Research Into Small Arms Technology (CRISAT), that was set in motion by Panel III after the Small Arms Post 2000 paper, was designed to define the target rather more exactly. Details and dimensions of soldiers in different shooting attitudes and the description of a number of vehicles and field fortifications are given in CRISAT Technology Area 1 (TA1) report.

Protection

Before the Panel III deliberations on post 2000 small arms, no full definition of the target had been laid down, except that it was an enemy soldier, lightly protected. The understanding was that this meant that the target was wearing a layered Kevlar waistcoat, weighing about 2.5kg, as Combat Body Armour (CBA) and a good steel helmet (equivalent to 3.4mm of mild steel). In CRISAT Report TA1, further details of the sort of personal protection that a target might be wearing are laid down. This is based on the Russian CBA and American PASGT helmet with a polycarbonate visor. The details of vehicles, helicopters and field fortifications are also given because such may need to be taken into account when determining the complete protection behind which a person may be operating. However the designer must be careful not to spoil the weapon by degrading its performance against the primary target, a person, by including a capability against other targets. Details of individual CBA are shown in Fig. 1.1.

This is made up of 12 overlapping plates of 1.6mm titanium over 20 layers of Kevlar, front and back, weighing a total of 3.9kg. For purposes of a crude comparison, this CBA is about the equivalent of 3.4mm of mild steel. The American PASGT, the helmet standard, is of similar equivalence. In order to have a good chance of incapacitating a person, it is necessary to penetrate this armour and still have enough residual energy to effect damage or provide multiple hits on the unprotected parts, whose synergistic effect would produce incapacitation.

Effect Required

CRISAT Technology Area 2 (TA2) laid down definitions of "Incapacitation" and

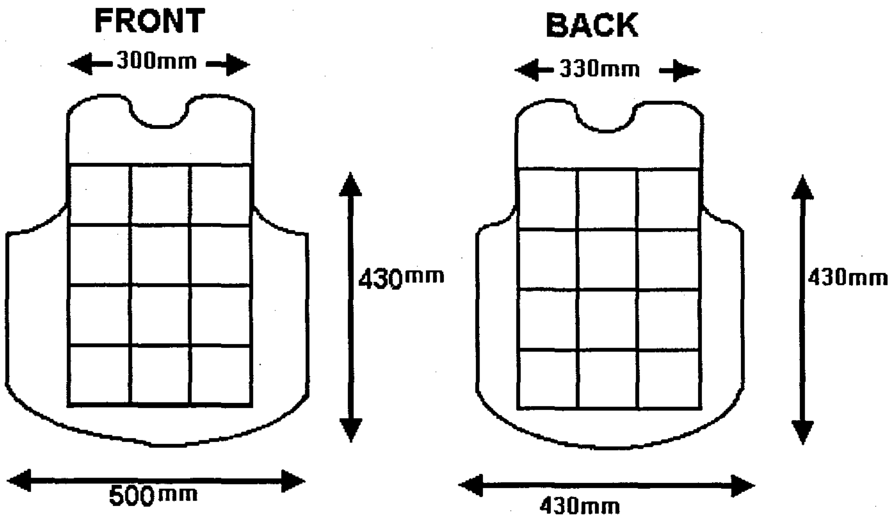


Fig 1.1 CRISAT Body Armour (based on Russian CBA)

"Suppression". Unfortunately most NATO Countries had a different method of measuring these effects, none of which were ideal. Work continues to find a common NATO-wide acceptable computerized model and a standard for the human body simulant.

Incapacitation

A person is "incapacitated" when unable to carry out their Primary Function. To this must be added a delay from hit to incapacitation and a duration for such incapacitation to last. Annex 2 of TA2 gives the following table:

Table 1.1 CRISAT Incapacitation Criteria

Distance to Target (m)	Delay (s)	Duration	Probability of Incapacitation (PI = PIH x PH)
0 to 100	< 1	5-10 min	0.9
100 to 600+	4 desirable 8 essential	3 hrs	0.9 desirable 0.75 essential

PI is the **P**robability of **I**ncapacitation.
PIH is the **P**robability of **I**ncapacitation given a **H**it.
PH is the **P**robability of a **H**it.

For incapacitation it can be seen that it is not necessary to kill or even wound a person! For example, a signaller would be incapacitated if one destroyed his radio set. Furthermore, the enemy may well be more inconvenienced and have its morale lowered further by a wounded person than by a dead one! People with different jobs will have different incapacitation criteria, but it should be possible to fairly closely define such criteria. Historically it has been accepted that if a projectile dumps 80J of energy into a body very quickly, then that person is likely to be incapacitated. This is a great over simplification, but some figure upon which to plan is needed. Wounds that result from the same amount of dumped energy will differ widely depending on the tissue disruption and any bone or vital organ struck. Indeed a bullet that breaks up during penetration will do much more damage than one that stays whole. However the "Law of War" set out in the Geneva and Hague Conventions forbids the employment of arms, projectiles or material calculated to cause unnecessary suffering or superfluous injury. Basically this means that bullets that are specifically designed to break up are outside military specification. Bullets normally become unstable in flesh and thus tumble (see bullet path diagram in Fig. 1.2). The maximum permanent cavity and thus the greatest effect is shown to be caused when the bullet is at right angles to the bullet path. TA2 goes into much more detail, including some work on the vulnerability of different parts of the body. Indeed Wound Ballistics is a subject in its own right.

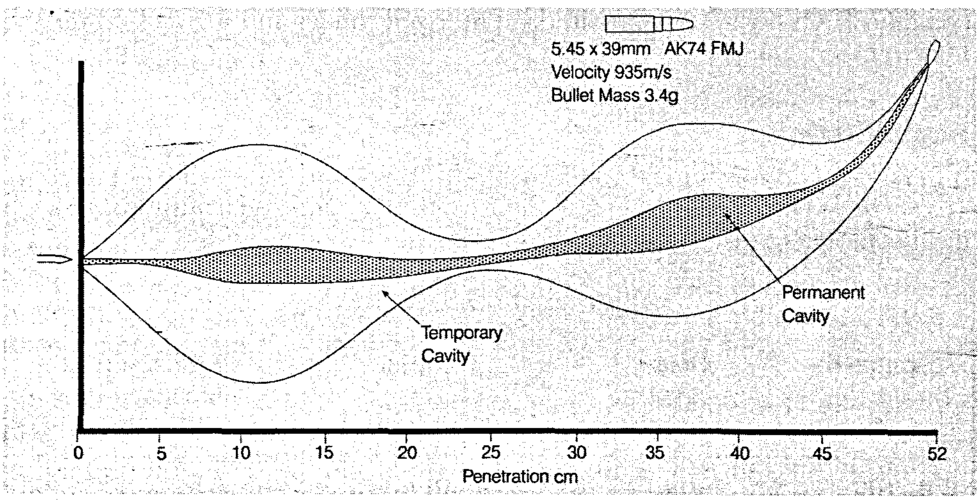


Fig 1.2 Typical Cavity caused by a High Velocity Bullet

Many authorities on wound ballistics maintain that wounding is dependent on a function as shown below, rather than pure kinetic energy dumped, but again this will not necessarily hold true:

$$E = \frac{m(v_I - v_E)^{\frac{3}{2}}}{2}$$

where: E = Energy transferred (J)
m = Mass of projectile (kg)
v_I = Impact velocity (m/s)
v_E = Exit velocity (m/s)

Analysis of results for different wounding criteria produces a graph like the one shown below:

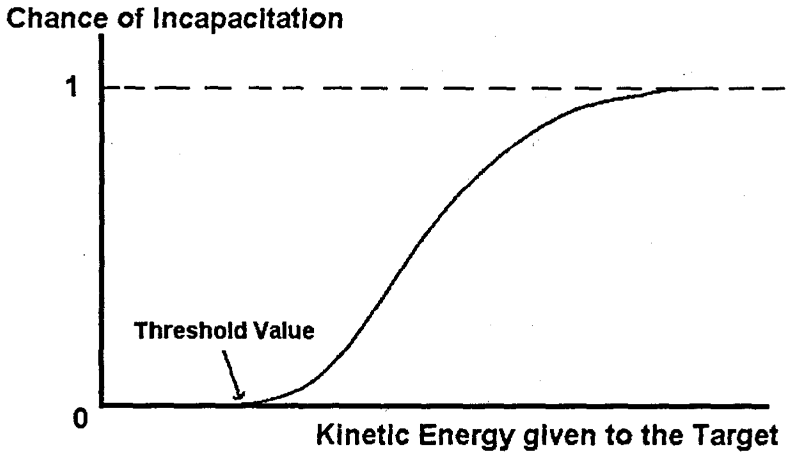


Fig 1.3 Graph of Chance of Incapacitation against Energy passed to Target

The above graph is of the form:

$$P_{IN} = 1 - e^{-a(mv^{3/2} - b^{n})}$$

Where P_{IN} = Chance of incapacitation given a random hit
m = Mass of fragment
v = velocity of fragment
a, b, and n are constants associated with the particular criteria being considered

Suppression

TA 2 states:
An enemy is "suppressed" when unable or unwilling to deliver effective fire, attempt movement or observation due either to injury or the fear of such.

Table 1.2 Suppression Criteria

Distance to target(m)	Delay in neutralization(s)	Duration of suppression(s)	Probability of suppression
Up to 2000	10	1st round perceived to last round perceived +5	0.75

Unfortunately, while incapacitation can be measured to some extent, suppression depends much more on the morale, extent of training and mental and physical state of the person being suppressed and is therefore an unmeasurable variable. However, a well trained, motivated and experienced soldier will need to be convinced that he will be badly hurt if he is to be suppressed.

Range

Considerable thought and research needs to be done to determine the effective range requirement for each weapon in the family. Statistics from past wars, and intervisibility in different climates and terrain, added to operational analysis, all help to make the correct choice. Indeed statistics from past wars using past weapons can, unless care is taken, skew the results and produce a less than optimum solution. After all a soldier is unlikely to engage a target much beyond the range that he can hit and hurt it. It is much better to work on the range that a target can be seen, aimed at and engaged successfully with up-to-date technology. CRISAT research used a mixed method to produce the graphs shown in Fig. 1.4 for section weapons. Each graph is of the form:

$$F_R = 1 - \{1 + (2R/\bar{R})\}e^{\frac{-2R}{\bar{R}}}$$

Where F_R = Cumulative Frequency
R = Range
$\bar{R}$ = Mean Range

Target Availability

For the Individual Combat Weapon (ICW) this means that, if a weapon is to be fully capable anywhere in the world, targets at all ranges up to 600m must be catered for. This is reinforced by statistics from recent conflicts that indicate that 95% of all rifle engagements occurred below 400m. Different criteria must be used to discover the ranges for PDW and MSW.

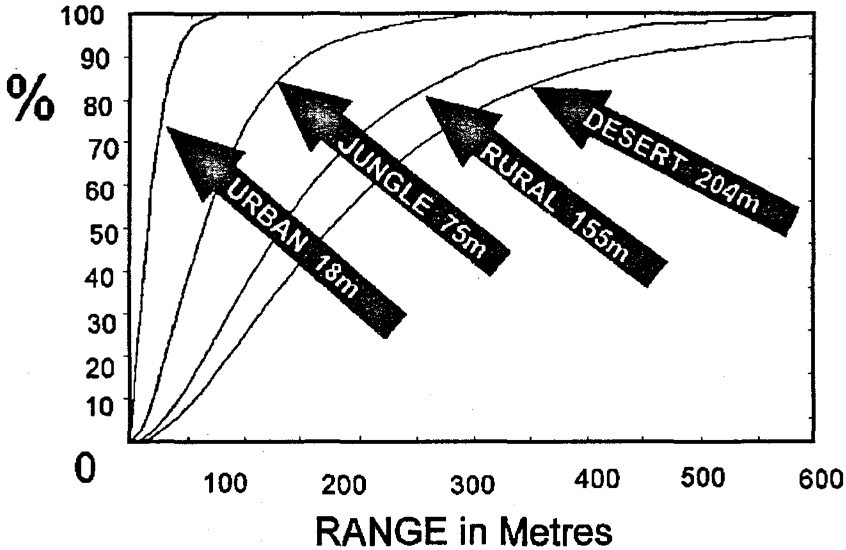


Fig 1.4 Target Availability in Urban, Jungle, Rural and Desert Scenarios

Other Factors Affecting Design

Ammunition Effect

The ammunition is the most expensive part of a small arms system. It tends to be used in great quantities especially when firing is mainly prophylactic. Increasing the cost of a round, for example by using a tungsten penetrator to improve performance, does not make economic sense, except for very specialist requirements. If, by some other means, one could considerably increase the hit chance, then more expensive ammunition could be considered.

Hit Chance

The first requirement is for "consistency". After that a method of "zeroing" provides "accuracy". However another problem concerns the estimation of range. As a general rule most people are 15 to 20% out in estimating any distance, short or long. In order to overcome this problem, muzzle velocities have been ever increasing to give a flatter trajectory. This works for ranges up to 300m for small calibre, light bullets. It does not work for heavier, sometimes HE, projectiles going to much greater ranges. One must also remember that, for a given bullet mass, increasing the velocity greatly increases the recoil unless the mass of the weapon is also increased dramatically.

Often forgotten is the effect of wind on the hit chance. With the help of laser range finders, fairly accurate range correction can be applied to a weapon. However the aim off required for wind is a matter of individual judgement

and can only be learnt by constant practice. Some people are better than others at judging distance and wind, but over fairly long ranges a miss is more likely than a hit. Another effect that is usually forgotten is that adding something, such as a bayonet, after one has zeroed the weapon, changes the zero substantially.

Weight

Since the infantryman is expected to carry everything he may need, often over considerable distances and in harsh environments, every piece of equipment needs to be of minimum weight consistent with ruggedness. However the mass of the weapon also affects the recoil felt by the firer. Somewhere under 5J of recoil energy is accepted as being comfortable and of course the lower the recoil, the easier it is to hold a burst on target. Some compromise is therefore needed. Indeed a mass of around 4kg in a 5.56x45mm rifle satisfies both requirements. It is interesting to note that the layout of future weapons is likely to be of a "bullpup" configuration. This means that the magazine comes behind the trigger. Weight can be saved using this configuration and the weapon can be easier to handle although the long extension needed from the trigger to the sear can cause problems. The high sight line of most modern weapons, with a "straight through" (barrel in line with the butt) configuration can also produce problems.

Reliability

Designing reliability into a weapon is a mandatory requirement. However it costs money to implement and prove. It is surely better to bring a fully trialled, modified and reliable weapon into service late, than a weapon that destroys the soldier's confidence and morale due to malfunctions in early use. Money spent wisely in this area can pay great dividends.

Ease of Operation

Very often simplicity and reliability go together. The multitude of requirements placed upon a weapon can cause a complex design. However, ease of operation can mean that the complexity is hidden inside the weapon and this can bring unreliability. Not only must the weapon be easy to master and clean but it must also be comfortable to fire and handle. Indeed the weapon must be compatible with NBC and cold weather clothing, helmets, and earpieces. A weapon must be made for easy and snag-free movement in the jungle, or crawling in mud and sand. Many demand that the weapon can be used off either shoulder in order to suit everyone and allow firing around cover both left and right. Great thought should be taken as to whether any benefits would outweigh the cost in time and money used to provide these features. Many forget that the zero of the weapon is not the same off both shoulders, nor are left-handers absolved from firing light anti-armour weapons that are only right handed!

Variety of Weapon Types

Reducing the types of weapon is an attractive idea, giving great benefits in training, maintenance, spares, types of ammunition, interchangeability and low cost due to a large quantity bought. But it can result in a compromise on design and a weapon less than suited to a specific task. Standardisation is another goal, but it is unlikely that any nation is willing to be fully dependent on any other. It is therefore likely that where ammunition standardisation may be agreed, the weapon to fire that ammunition will stay as a nation's choice. If someone produces new, maybe revolutionary and better ammunition, even standardisation in this area may fail. National interests and prejudices can also play a part, as was the case with 7.62mm, 5.56mm; and no doubt would have been again if 4.73mm caseless round had been successful. It should be noted that commonality of the actual round in a section is not sufficient. For example, the Americans with both the magazine fed M16 and the belt fed M246, have two sorts of ammunition in their sections. While NATO has standardised many of the ammunitions used, the weapons to fire them are usually made or chosen by the country itself, often on political or economic grounds.

Ambidextrous Firing

Many people feel strongly that, if a weapon cannot be fired off either shoulder, then a version should be provided for firing from the "wrong" shoulder. So long as the eye used for aiming is capable of reasonable vision, it has been shown that anyone can be taught to fire off either shoulder. There are then benefits to be had in only making a weapon for the majority of users. It should also be remembered that there are no left-handed LAW. A weapon that can be fired off either shoulder would be the ideal, but training would be needed if the full benefit of such a weapon was to be realised. The next heading also impinges on the variety of weapons.

Cost

While it has already been seen that reliability, ease of operation and variety affect cost, training and maintenance time along with spares also add considerably to the overall costs of a weapon system. While, at times, cost seems to drive everything, it is very dangerous to allow it to dominate.

Safety

While it is obvious that an unsafe weapon will not see service, too many safety features can be designed into a weapon, thus rendering it almost unworkable. While the designer must ensure mechanical safety and provide a "safety catch", it is also essential today that the weapon has design safety. What this latter means is that the weapon cannot be assembled incorrectly or with a vital piece missing thus rendering the weapon unsafe to fire. Whereas today's technology may allow one to have small yet strong working parts, these must not be easily

dropped and thus lost, rendering the weapon useless.

Defeating the Target

The User must clearly define the target and the range at which he requires the target to be defeated. These criteria should be based on tactical factors such as weapon role, normal fields of fire in the expected terrain and the availability of other supporting fire. Defining the target can prove to be the most difficult part of the Staff Requirement to decide, particularly as the user will be tempted to obtain the longest effective range from the lightest possible round and weapon. These three factors are not necessarily compatible. Any increase in target specification during the development of a weapon system invariably leads to delay and added costs. On the other hand there is little point in providing soldiers with a weapon that is ineffective against their likely target so the designer and user should examine their other variables critically, particularly range and recoil. If this discipline is not followed then the soldier will suffer, as so often before, with an unnecessarily heavy load of weapon and ammunition. Incapacitating the unprotected man is relatively simple. However, once the target becomes a man behind cover or wearing protective clothing, the problem becomes much more difficult. The table below indicates the approximate strike energies needed by single bullets of two different calibres to defeat various targets. The figures assume that the bullet strike is perpendicular to the face of the material.

Table 1.3 Approximate Energy Required to Penetrate Certain Targets

Target	5.56 x 45mm NATO Ball (SS109)	7.62 x 51 mm NATO Ball
Unprotected Man.	80 J	80 J
NATO Plate (3.4mm mild steel).	325 J	900 J
Combat Body Armour (1).	225 J	800 J

Note (1) The CBA that is envisaged in this table is 2.5kg Kevlar or equivalent.

As the calibre increases the energy required to penetrate protection also increases. This is because the energy is applied over a greater area of the target's protection. Thus penetration is dependent upon the residual energy at a particular range and inversely upon the cross-sectional area of the bullet. The concept of Kinetic Energy Density may be used as a rough guide to assess and predict penetration capability.

Although it is not shown in the table, it should be noted that the 9 x 19mm Parabellum round used in most SMGs and pistols requires 1000J to penetrate 3.4mm of mild steel. The muzzle KE of approximately 550J of the standard 9 x 19mm round is even ineffective against a protected target at point blank range.

- Having penetrated the material, the bullet will still require a minimum of 80J of residual energy to incapacitate a man. This value of 80J has been used for almost 100 years. However recent tests have shown that a 5.56x45mm NATO bullet, with 80J of residual energy after perforating CRISAT CBA , will penetrate a further 300mm of ballistic gelatine. 80J can therefore still be taken as a realistic value for incapacitation.

- The incapacitation requirement is usually coupled to a certain protection piercing performance. The penetration of the most difficult part of the person's protection is accepted as sufficient for small arms ammunition. The NATO target protection specified earlier is approximately equivalent to 3.4mm mild steel plate. The penetration of wood, sand, etc, used in field fortifications, or the materials of a vehicle in which the person may be travelling is not usually considered in the specification of normal ammunition, but would need to be taken into account for any specialized requirement.

Efficient Bullets

Given that any bullet should be made with the best possible aerodynamic shape, then to provide good carrying power a high Ballistic Coefficient (C_0) is required. But,

$$C_0 = \frac{m}{K_0 d^2}$$

Where m = Mass of the bullet
d = Diameter of the bullet
K_0 = Shape and steadiness factor

Therefore the designer tries to achieve a high value for m/d^2. This would lead one to design a bullet with the highest average density possible and a large diameter.

For a bullet to remain stable it needs a high (over 1.6) Stability Coefficient (S). But,

$$S = \frac{A^2 n^2}{4B\mu}$$

Where A = Axial moment of inertia for projectile
n = Spin rate
B = Transverse moment of inertia
μ = Aerodynamic coefficient dependent on shape that increases rapidly with increase in projectile length and to a lesser extent with increases in diameter.

Unfortunately, A will be high if the diameter is large, while B will be small if the length is short. This should lead to a short, fat bullet design, but while this would give good carry and low spin rate, it does not satisfy the next criteria.

Penetration

For good penetration, one would ideally design a thin bullet of high mass. This means choosing the highest length/diameter (l/d) ratio possible. Indeed an indication of a bullet's capacity for penetration is its energy density.

$$\textit{energy density} = \frac{\textit{muzzle energy}}{\textit{cross-section}}$$

$$= \frac{4\, m\, v^2}{2\, \pi\, d^2}$$

However, this is not the complete answer, because the make up of the bullet also has a bearing on the penetration. The round that was selected after the 1978 NATO competition was the SS 109. This has a steel tip with lead behind. The lead tends to force the steel tip through the target. While lead is denser than most other bullet metals, steel and tungsten are better for penetration. Any choice or mix is thus a compromise.

Loss of Kinetic Energy (KE) with Range

All bullets lose energy as they go down range. From the graph in Fig. 1.5 it can be seen that NATO 7.62mm ball still has enough energy to incapacitate an unprotected person out to 2000m. For this reason it is still used in medium or crew served support weapons. Both NATO 7.62mm ball and 5.56mm SS109 type bullets are equally effective at penetrating a 3.5mm mild steel plate at 600m.

The 5.56 x 45mm NATO (SS109) and the Russian 5.45 x 39mm rounds are lighter than the 7.62mm and have less KE, hence their reduced effective range. The 5.56mm NATO round retains more than 80 J out to 1200m, while the 5.45 x 39mm and 9 x 19mm rounds lose the lethal KE value within 1000m. Possession of more than 80 J is not a true minimum energy limit. The real measure is that the bullet must transfer this level of energy to the human body. This transfer is achieved by the bullet slowing down within the body. At battle ranges small arms bullets tend to have considerably greater energies than 80J and even if they pass straight through the body, there is likely to be a transfer of energy greatly in excess of that value.

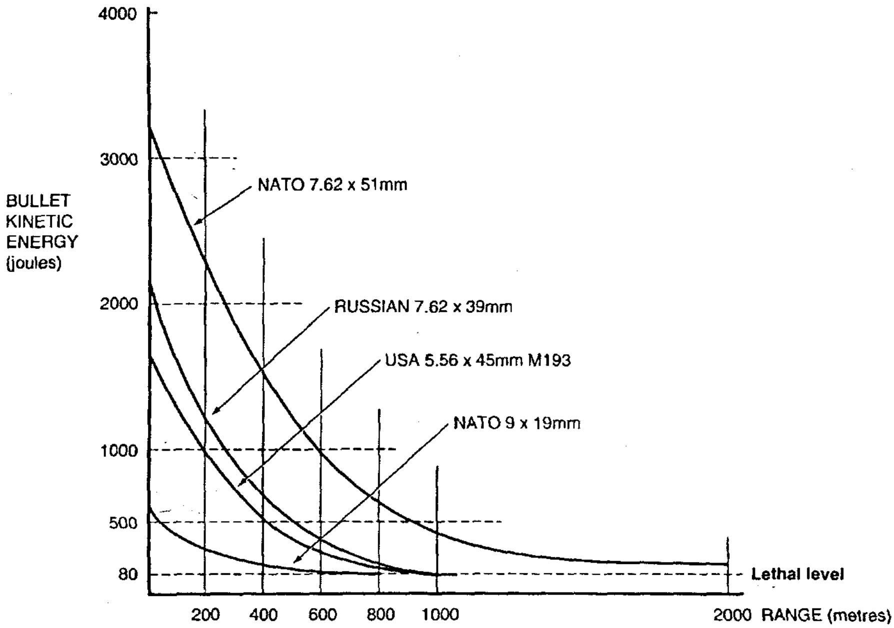


Fig 1.5 Kinetic Energy with Range for Different Bullets

Table 1.4 Ranges at which Targets are Penetrated

Target	5.56 x 45mm NATO Ball (SS109) (m)	7.62 x 51mm NATO Ball (m)
Unprotected Man.	1200	> 2000
NATO Plate (Helmet).	640	620
Combat Body Armour (Kevlar CBA only)	750	900

Notes Figures for NATO plate and Aluminium armour are those achieved in NATO trials 1977-78. Remaining figures are calculated.

In practice, effective ranges for incapacitation of protected targets are slightly shorter as the bullet must carry the incapacitating dose of 80J in addition to the penetration energies. The minimum terminal ballistic performance is defined as penetration of 3.4mm of mild steel, plus a remaining energy of 80J to incapacitate the target. The terminal energy level indicates the effective range of the ammunition. For high velocity streamlined projectiles this range tends to lie within any limitations caused by tracer burn out and hit probabilities.

Hit Probability

The chance of a hit with a single shot depends largely on the bullet trajectory being sufficiently flat to eliminate range estimation errors, the weapon being correctly zeroed and the firer adopting the correct point of aim and holding a steady aim picture. When firing bursts, the interaction between weapon and firer becomes important. The first round is likely to go where the firer aimed, but subsequent rounds are most unlikely to follow the same trajectory. The consistency of the burst will depend largely on the firer's ability to hold the weapon on the original point of aim although some weapons are better than others in this respect. Unless the barrel is supported by a bipod the chance of a hit at long range is small.

Vertex Height

The distance dropped by a bullet, if wind resistance is neglected, can be expressed by:

$$s = 0.5gt^2$$

Where s is the vertical drop, g the acceleration due to gravity and t the time of flight.

Air resistance, of course, slows a bullet in flight horizontally, but also slows its vertical fall, so that, for short ranges at a given time, an approximate relationship exists between range and drop for given muzzle velocities, as shown in the table below

Table 1.5 Bullet Drop .v. Range for Various Muzzle Velocities

	Vertical drop during time of flight (m)					
	0.05	0.2	0.44	0.79	1.23	1.77
Muzzle velocity in m/s	Horizontal range (m)					
1000	100	200	300	400	500	600
850	85	170	255	340	425	510
700	70	140	210	280	350	420

If an average human target is assumed to be 1.6m high and the point of aim is central, then there is a 0.8m margin for vertical error. For weapons with muzzle velocities in excess of 800m/s a single sight setting should be adequate for ranges up to 300m. The table also shows how very sensitive to correct sight setting accurate fire from weapons with slower muzzle velocities must be.

Wind Correction

No discussion of the correction that a firer needs to apply due to the wind is shown here. It is a factor that greatly affects hit chance and would need to be taken into account. However, it must be mentioned that some bullets, flechettes in particular, are more affected than others. In general, the lighter the bullet, the worse the effect.

Recoil

The momentum of the bullet and the propellant gases going forward have to be balanced by the momentum of the weapon going backwards. The recoil energy is felt in the firer's shoulder. The factors that determine the recoil are the weapon mass and bullet momentum, as shown in the following equations:

$$MV = v\,(m + \beta c)$$

Where M = Mass of the weapon.
V = Free recoil velocity of the weapon.
v = Muzzle velocity of bullet.
m = Mass of the bullet.
c = Charge mass.
β = A propellant constant which depends on the efficiency of the system. It normally lies between 1.5 and 1.8 and is found by experiment.

The term free recoil is used because it is assumed that the weapon recoils without restraint. In practice, the shoulder of the firer resists recoil movement, thus the energy equations need to be modified. However the effect is usually small and the computation easier if ignored.
An approximate value can be found from:

$$\beta = \frac{\sqrt{(v^2 + 1\mathrm{x}10^6)}}{v}$$

From this $V = \dfrac{v(m + \beta c)}{M}$

The mechanism of recoil has never been fully explained in mathematical terms but the following simplification gives an adequate prediction of weapon recoil behaviour. Weapon recoil energy can be expressed as:

$$\text{Recoil Energy} = \tfrac{1}{2}MV^2$$

$$= \frac{\tfrac{1}{2}Mv^2\,(m + \beta c)^2}{M^2} = \frac{\tfrac{1}{2}v^2\,(m + \beta c)^2}{M}$$

Bullet momentum and the associated gas momentum are likely to be indicated fairly precisely by the terminal energy requirement for the bullet to defeat the target at a particular range. The user will wish to reduce the weapon mass to a minimum, but this is often dictated more by the strength needed to withstand rough handling than by consideration of momentum. However, the user will also wish to keep the kick of the weapon, in the firer's shoulder, low, though this should not be considered as an end in itself. Weapons with less recoil would undoubtedly be more pleasant to fire, but should not be chosen on that score alone, particularly if lethal range is lost. At first sight this might be considered the case with the 5.45 x 39mm AK74 with its very low weapon mass and low recoil. However, the AK74 is intended as a relatively short range assault rifle firing on automatic and therefore its parameters are not as strange as they appear.

Recoil can be measured on a ballistic pendulum. If h metres is the height that the weapon rises, then the work done is Mgh joules.

Therefore $\frac{1}{2}MV^2 = Mgh$

$$V^2 = 2gh$$

Table 1.6 shows the free recoil energies for a selection of small arms.

Table 1.6 Free Recoil Energies of Various Weapons

WEAPON	Round SIZE in mm or in	Weapon MASS in kg (1)	Bullet MASS in g	Charge MASS in g	M V in m/s	Recoil VEL in m/s	Free Recoil recoil ENERGY in J
DB Shotgun	12 Bore	3.00	33.14 incl. Wads	2.64	330	4.08	25.0
No. 5 Rifle	77x56R (.303)	3.2	11.49	2.40	729	3.39	18.4
No. 4 Rifle	77x56R	4.07	11.49	2.40	748	2.74	15.3
L1A1 SLR	7.62x51	4.57	9.33	2.85	838	2.48	14.0
AKM Rifle	7.62x39	3.45	7.97	1.62	715	2.15	8.0
AR 15 Rifle	5.56x45	3.04	3.56	1.56	1000	1.94	5.7
Ingram SMG	11.4x23 (.45 ACP)	3.19	15.16	0.32	280	1.37	3.0
AK 74 Rifle	5.45x39	3.45	3.45	1.37	900	1.44	2.5/3.6 (2)
L85A1 Rifle	5.56x45	4.1	4.0	1.63	947	1.39	4.0
M16A2 Rifle	5.56x45	3.35	4.0	1.63	947	1.82	5.5
H&K G11 Rifle (Caseless)	4.73x33	3.8	2.35	2.95	930	1.51	4.3 (3)
L2A1 SMG	9x19	3.21	7.45	0.39	390	0.97	1.5
HK 33 Rifle with Insert	5.58x15.11R (.22LR)	4.3	2.6	0.10	310	0.23	0.1

Notes:

(1) Empty magazine.
(2) Without muzzle brake/compensator.
(3) In 3 round, 2000 rpm, burst, it is claimed that recoil energy is not experienced by the firer until after all rounds have left the barrel.

Recoil Impulse

While recoil energy is the usual measure, a firer will often feel that one weapon rather than another is nicer to fire although the recoil energy from both is the same. This is due to the impulse felt by the firer. The weapon with the higher recoil force applied over a shorter time will feel worse than a lower force over a longer time. This often results in a recoil operated weapon being preferred by a firer from the purely feel point of view, rather than one with the same recoil energy but using a different operating method.

Muzzle Brakes

Another way to alleviate the recoil is to use a muzzle brake. It is of interest to note that the Russians have used the brake on the AK74 to provide some pull off compensation at the same time as cutting down the recoil. This is achieved by redirecting some of the gas following the bullet high and right through two holes and having the single baffle slightly offset to add to this effect. The problem, with what would at first appear a good idea, is that a compensator works for one person in one position. It does not work the same way for different people and even one person gets a different result in different firing positions. To add to these problems, a muzzle brake is a poor flash hider.

The effect of a muzzle brake is to change the direction and hence the momentum of the propellant gases after shot exit. If the gases continue to expand in passing through the baffles of the muzzle brake, the passages will form a divergent nozzle and enhance the thrust on the baffles. The total change in momentum in the muzzle brake results in a forward impulse on the recoiling weapon mass.

If E_0 = The free recoil energy without the muzzle brake.
and E_B = The free recoil energy with the muzzle brake..
then efficiency of the brake $(\eta) = \dfrac{E_0 - E_B}{E_0}$

The gas impinging on the muzzle brake will affect the impulse of the gas action. In a perfect system, the direction of all the propellant gases would be reversed but the mean velocity would remain the same. Thus the impulse from the propellant gases would be a negative value. Hence, ignoring the mass of the muzzle brake as being very small compared with the weapon mass:

$$mv + cv(1-\beta) = MV$$

Then
$$\eta = 1 - \frac{[m+(1-\beta)c]^2}{(m+\beta c)^2}$$

The sort of result (72%) obtained from such an equation is never achievable in practice because it is not possible to reverse the flow of the muzzle gases nor catch all of them in the baffles. Therefore, in practice, efficiency well below 30% can be expected.

Vehicle Mounted Machine Guns (VMMG)

It is often not appropriate to take a section MG and adapt it for mounting in a vehicle. In most cases the role of the weapon and the range that is required of it are very different. Added to which the mounting will necessitate a much different approach than the open air ground mounted version. Some of the differences that must be addressed are:

1 Easy access to the weapon when installed is required so that immediate actions and stoppage drills can be carried out. Short in board length would be an advantage, thus using the minimum amount of turret space.

2 Because high rates of fire and long bursts are commonplace, barrel changing must be quick and easy in the confined space of a turret. It would also be sensible to utilise a heavy barrel so that the necessity for barrel changes will be less frequent than for the section version in which lightness is more important.

3 The cyclic rate must match the target. This may necessitate at least two rates of fire. Only a low cyclic rate of fire is needed to provide prophylactic or suppressive cover against probable enemy infantry positions. When engaging a moving target, such as an aircraft or helicopter, a much higher rate of fire is called for. This is possible, but not easy, to achieve in propellant powered guns. With externally powered guns, a change in the electrical voltage to the motor, can move the rate of fire up or down.

4 Empty cartridge cases and links need to be disposed of, without them being allowed to get into the turret turntable or any other unwanted space. Outside the vehicle is ideal. Collecting links is always difficult because they tend to catch on one another and thus back up until they cause a jam and a stoppage that is time consuming to rectify.

5 It is also an advantage to have a weapon that can be made to feed from either side without the need for extra parts or tools. This will allow such a weapon to be fitted to vehicles already in service without too much fuss.

6 Because a VMMG is normally placed in a turret, the minimum amount of fumes should be allowed to pollute the air inside it. This makes externally powered and recoil operated weapons preferable in turret mounts.

7 Because the weapon must protrude through the turret armour, the hole required must be small, in order to retain its integrity. A weapon based upon the infantry section or sustained fire versions is often not optimised to allow this.

8 Standardisation of the gun and ammunition with the section version often means that the weapon is not capable of taking on the rather different targets that an AFV is required to engage. This can also be the case with the range at which such targets are to be engaged.

9 The design of the gun will also be dictated by the need to dismount it. Obviously a weapon that requires some external power source is not going to be easily dismounted.

10 Frequently in turret mountings, the belt of ammunition must be pulled through a convoluted feed system and over a long path. This means that the weapon must be able to provide a powerful pull and that the belt links can withstand it.

Added to this list must be those characteristics common with a dismounted MG, such as:

11 Reliability.

12 Low weight.

13 Long gun life.

14 Consistency (Accuracy).

Designation of Ammunition

Ammunition is designated by its calibre. However this is not enough to avoid confusion. The length of the cartridge case is normally also required e.g. 7.62 x 51mm as against 7.62 x 39mm. In certain cases even more information is required to differentiate between ammunition e.g. 5.56 x 45mm (M193) as against 5.56 x 45mm (NATO), the latter is based on the Belgian SS109 design. Further refinements can be added to show the make up of the cartridge case e.g. 7.62 x 54 Rmm, which indicates that this round has a rimmed case.

Approximate Stowage Requirements for Ammunition

As a useful approximation, the volume and weight and thus the stowage required for standard bottle shaped ammunition is proportional to their calibre cubed.

Thus $1000 \times 7.623 = \text{quantity} \times 20^3$

Or only 55 x 20mm rounds will fit into the space occupied by 1000 x 7.62mm rounds.

Conclusion

It is the bullet that does the damage. The weapon is only a means of firing it and getting it on its way to the target. Therefore it is the ammunition that must be designed first and then the weapon follows.

2.
Other Support Weapons

Grenade Machine Gun (GMG) or Automatic Grenade Launcher (AGL)

One way to overcome the problem of bullets losing lethality as they travel down range is to deliver a high explosive payload. Both the Russians with their AGS17 and the Americans with their Mk19 have produced GMGs. Both these weapons have their proponents, having proved effective in Afghanistan and Mogadishu. However, there are some disadvantages to these weapons.

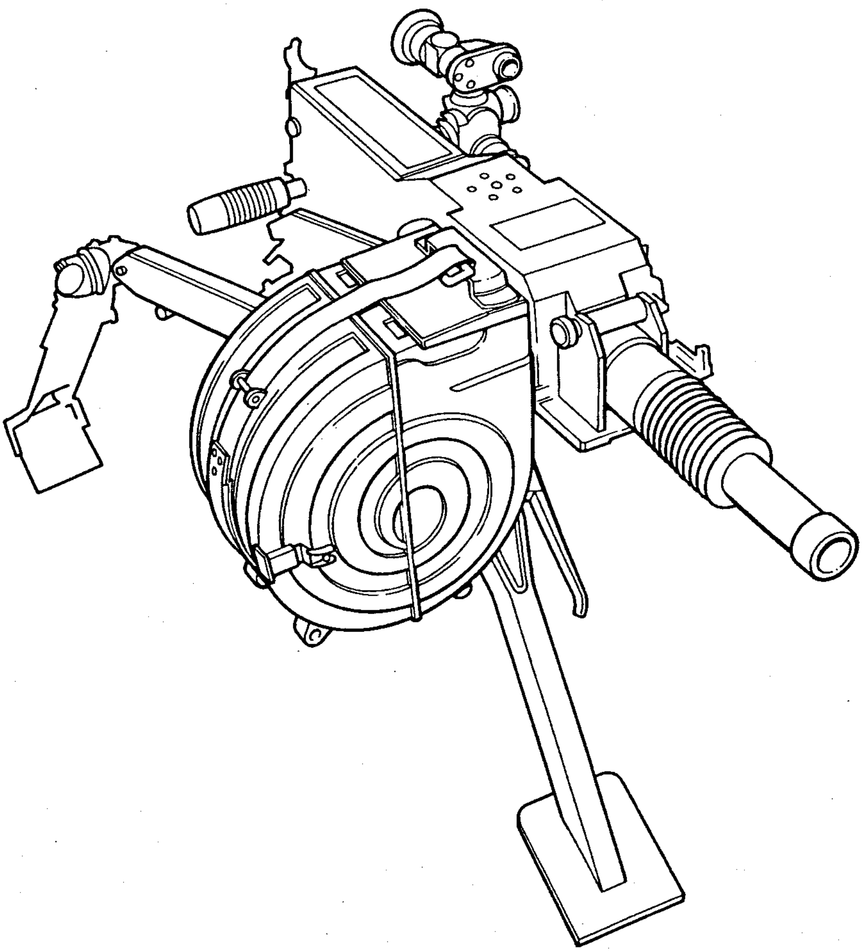


Fig 2.1 Russian AGS 17

Weight of Weapon

The two weapons mentioned above both use a form of blow back, pure for AGS17 and the advanced primer blow back method for the Mk19. This leads to very heavy working parts. A good stable tripod is needed and this adds to the all up weight.

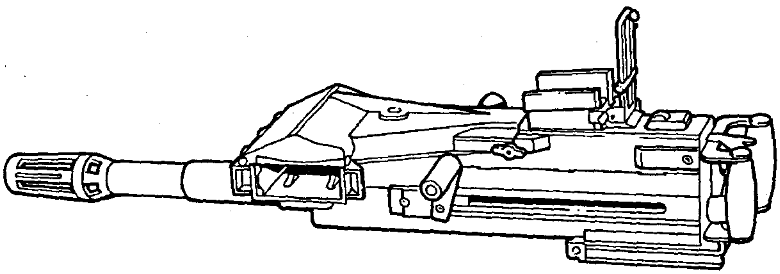


Fig 2.2 American 40mm Mk 19 MOD 3

Ammunition

The design of the ammunition is not being discussed in this book. However, it needs to be pointed out that the ammunition is both heavy and expensive. In particular the Mk19 ammunition links are complex and costly. The velocity of the round is low, resulting in a very high trajectory and the need for accurate range estimation if a first burst is to come near to the target. The number of lethal fragments that can be produced from even a 40mm grenade ground burst is limited. Much of the payload is taken up with safety, arming and fuze mechanisms. A better effect could be achieved with air bursting munitions, but this would increase the complexity and cost greatly. However 40mm ammunition is well established and available in quantity.

Other Methods of GMG Operation

While the Germans and the Singaporeans have made blow back operated GMGs, the Spanish and South Africans have opted for recoil operation, which should, in theory, make for a lighter weapon and one that is much more easily controlled when firing a burst.

Conclusions

While such weapons have a place in the inventory of armies, financial restrictions may preclude a nation having both this form of weapon and a GPMG. Both weapons have advantages and any choice, whether for a mix, or just one, must be carefully made. Political considerations may be the determining factor, since any weapon projecting HE rounds may be unacceptable, especially in operations less than war.

3.
Small Arms Ammunition

A complete round of small arms ammunition is normally made up of four main parts:

- Cartridge case.
- Ignition system.
- Propellant charge.
- Projectile.

Cartridge Case

The cartridge case is designed to house the propellant charge, hold the ignition system, retain the bullet, protect the propellant from the hot barrel and to obturate the breech, i.e. seal the breech and prevent the escape of the propellant gases.

A large propellant charge is required in modern high performance small arms ammunition. To accommodate this charge in a round of convenient length, the body of the cartridge case is made larger than the diameter of the bullet (see Fig 3.1). The forward end is necked down to accept the bullet and the whole case is tapered along its length to enable the fired case to be extracted more easily from the chamber. Ammunition used in short range weapons, such as pistols and sub-machine guns, are of lower velocity and operate at lower chamber pressures, thus using much less propellant. The sides of the cartridge cases can therefore be made parallel. Parallel cases are also required for certain operating mechanisms used in low powered weapons, such as blow back operated weapons to give good obturation as the case moves back on extraction. Fig 3.1 shows the typical construction of high and low velocity small arms rounds.

Materials Used

Cartridge cases are generally made from 'cartridge brass' which is a 70/30 copper zinc alloy with the proportion of other elements being controlled to less than 0.25%. Cupro nickel is another material sometimes used and is a copper nickel alloy of about 80/20 proportions. Steel is often used in Eastern Europe: normally it is lacquered or has a copper wash to protect it from corrosion. Aluminium alloys are also sometimes used, especially where the saving of weight has an exceptional priority, i.e. for aircraft gun ammunition. However, cases need to be well protected from corrosion and there is the problem of the susceptibility of aluminium cases to rupturing when the external surface is

scratched or scored.

Plastic is also commonly used, especially for low pressure ammunition such as shotgun ammunition and blank rounds. For high pressure rounds the thickness of the case would be such as to reduce the internal volume to an unacceptable level. There is also a potential problem of the heat from a hot chamber with most plastics, which degrade at temperatures encountered in sustained fire weapons.

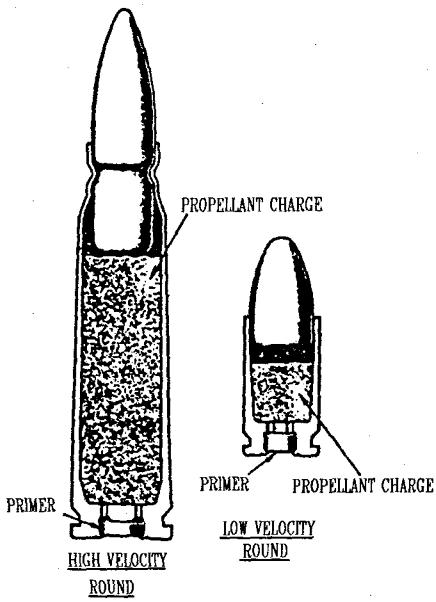


Fig 3.1 Typical Construction of Rounds.

Cartridge Case Manufacture

Brass cartridge cases are deep drawn from a disc, stamped from a sheet of material of correct thickness and condition. This deep drawing is completed in several stages with one or more intermediate annealing treatments being applied to remove the stresses and restore the material to its correct condition before the next operation. Steel cases are produced from bar stock from which they are deep drawn. To enable the deep drawing process to be carried out successfully it is necessary to anneal between each operation and to use a special lubricating procedure based on phosphating. A final annealing process is applied to cases of all materials to give it the correct degree of hardness; this may be applied uniformly (low velocity cases) or to form a gradient with the hardness decreasing from the base of the case forward. The soft mouth is necessary so that the case will start to expand as soon as the pressure rises in the chamber. This gives an early seal and prevents gas leakage and wear at the front of the chamber. Strength is required towards the base to enable the case

to withstand the internal pressure and rearward thrust from the propellant gases. The base must also withstand the stresses applied by the extractors when they first ease and then extract the empty case from the chamber. Fig 3.2 shows the hardness gradient along the length of a 7.62mm calibre NATO brass case.

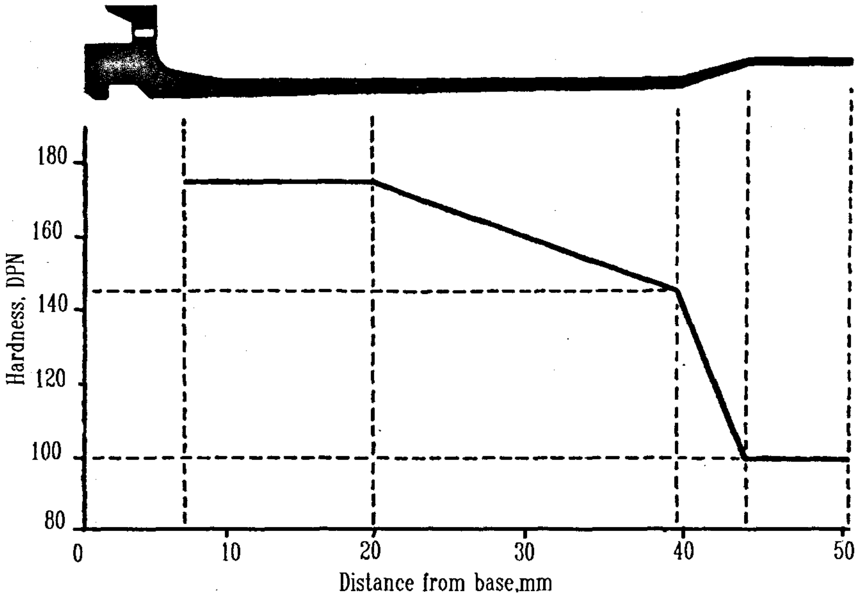


Fig 3.2 Hardness Gradient of a 7.62mm NATO Cartridge.

Steel is often used for cartridge case material because the material costs are lower than that of brass. The use of steel enables the case to be made thinner for the same strength, which increases the capacity of the case for the propellant. In addition, case weight is reduced because of the thinner section and the lower specific gravity for steel (7.85) compared to that of brass (8.5). An important difference between steel and brass is their Young's Modulus, which is the ratio of stress to strain. Young's Modulus for steel is 50% greater than for brass, so that, for the same stress, a brass case will deform more than a steel one. More importantly, a brass case will contract more when the internal pressure is released so the brass case will be easier to extract from the cartridge chamber.

The design of the forward end of the cartridge case is influenced by the bullet to be accommodated. The bullet has to be secured in the mouth of the case in such a way as to provide:

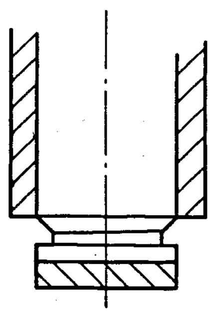
- A seal against ingress of moisture.
- Protection against accidental removal.
- Retention by the cartridge case.

The case must retain the bullet for a sufficient period after firing to allow gas pressure to build up sufficiently to achieve peak performance. This is known as 'shot start' and must be consistent from round to round to give regular muzzle velocities. Another important feature is that the bullet must be retained with sufficient strength that it is not dislodged during transit and as the cartridge travels through the feed system during loading and unloading. This is achieved by crimping the case so that a consistent force, known as 'bullet pull', is needed to unseat the bullet. A typical minimum bullet pull requirement is 267N for a 7.62mm NATO ball round.

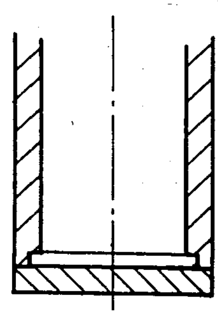
The feed and extraction mechanism of the weapon and the ignition system to be housed dictates the design of the base of the cartridge case. Two types of base have been used most often in small arms ammunition, these are shown in Fig 3.3 and are:

- Rimmed.
  The rim is used to position the round in the chamber and to facilitate extraction. This type of base is not normally used in modern automatic weapons as the rims can catch behind each other in a magazine and cause stoppages. It is also necessary to pull the round backwards to remove it from the belt of a machine gun, thus making the feed mechanism more complex than those where the round can be removed by pushing it forwards.

- Rimless.
  An extraction groove is machined round the base of the case to enable the round to be fed into the breech of an automatic weapon without becoming interlocked. The cartridge can also be removed from a cartridge belt by pushing it forward which makes the feed system relatively simple. Rimless rounds are positioned in the weapon by the shoulders of the case.



Rimless



Rimmed

Fig 3.3 Types of Rim and how they are Supported

Methods of Ignition

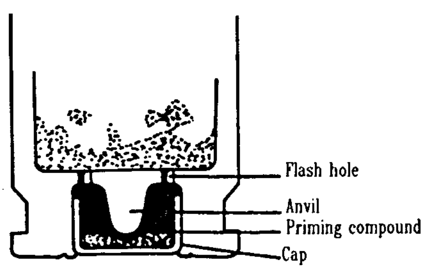
The system generally used in small arms ammunition relies on the use of an impact sensitive chemical compound. A striker in the bolt of the weapon strikes the primer and indents it, thus crushing the sensitive composition between the cap and a projection in the base of the cap called an anvil. The resultant flame passes through fire holes to the propellant.

Three types of ignition systems are used in service ammunition, they are:

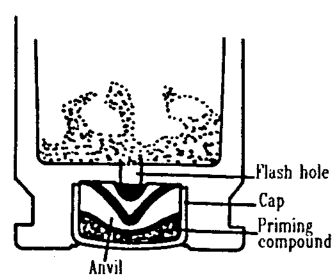
- Cap and Integral Anvil (Berden Primer). A percussion cap chamber is formed in the base of the case and connected by two fire holes to the interior of the case. In the centre of the chamber is a projection from the base of the case which acts as an anvil.

- Cap and Separate Anvil (Boxer Primer). The anvil is an integral part of the percussion cap and has two holes or vents machined into it for the passage of the flame on firing. The cap chamber is connected to the interior of the case by a single fire hole.

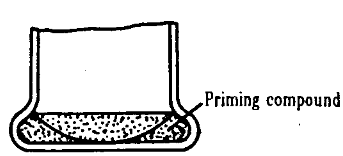
- Rim Fire. This system is used mainly in .22in ammunition and dispenses with the percussion cap and anvil in favour of a hollow rim formed internally in the base of the cartridge case. The primer compound is mixed with hard sharp particles (usually ground glass) to act as anvils when the rim is crushed by the firing pin. Fig 3.4 shows the different percussion ignition methods used.



Integral Anvil



Separate Anvil



Rim Fire

Fig 3.4 Different Methods of Percussion Ignition.

Electrical primers are not currently used in military small arms ammunition but there are examples used in sporting ammunition in which the primer is a semi-conductor device which is initiated by an electrical current applied via the firing pin. Work on military electrical small arms primers is currently being undertaken to enable greater control of the weapon functional cycle.

Materials used in percussion caps must have the following qualities:

- Expand easily to give efficient obturation.
- Be sufficiently strong to withstand the striker blow, without being pierced, and the explosion of the cap composition.

Drawn cartridge brass, cupro-nickel or copper alloy caps are extensively used. After fitting, the caps are closed with tinfoil or paper discs that are varnished over to produce an airtight seal.

In order that the cap may fit tightly in the cap chamber and prevent rearward escape of the propellant gas, known colloquially as 'caps out', one of the following methods is employed to secure the cap firmly in the chamber.

- Press fit. Used for low pressure rounds such as blanks and rifle grenade cartridges.
- Ringing. After inserting the cap in the chamber, a circular tool slightly larger than the cap chamber is pressed against the base of the case, forming a ring concentric with the cap chamber and pressing a metal lip over the edge of the cap.
- Burring. A special type of ringing used for very high pressure small arms ammunition, such as proof rounds, that produces a stronger metal lip.
- Stab punching. The cartridge is indented in a number of places over the edge of the cap.

Bullets

The ogive of high velocity (super-sonic) bullets is made to be well pointed to reduce aerodynamic drag. It is also usual for the base of the bullet to be tapered (boat tail) to reduce base drag when the velocity falls to sub-sonic. To increase stability in flight the ogive portion is often filled with a lightweight material to move the centre of gravity of the bullet more towards its base. To achieve forward obturation the bullet is made to the same diameter as the grooves of the rifling. The rifling lands deform the jacket of the bullet, a process called engraving, and the angular twist of the rifling profile imparts spin to the bullet to give it gyroscopic stability. 'Set up' also occurs which is the expansion of the

rear end of the bullet by the high pressure propellant gases which assists forward obturation.

All military bullets are of composite construction. Solid lead is not used because of its low strength and because a solid lead bullet, when used with high chamber pressures and high muzzle velocities, results in the coating the bore of the barrel with layers of lead which soon fills the rifling grooves. The most common construction is lead antimony alloy covered with a copper alloy envelope. Steel jackets may also be used to increase the strength of the bullet and to reduce material costs. Steel jackets usually have a copper wash to protect them against corrosion and to help reduce the high rifling engraving forces associated with steel jackets. This gives them the appearance of a copper alloy jacket.

Tracer bullets are commonly used with automatic weapons so that the firer can see the bullet in flight which acts as an indicator or weapon aiming aid. It is usual to have a dark trace followed by a bright trace to make it more difficult to detect the position of the firer. Recently, dim trace rounds have been produced that can only be seen using an IR sight. Fig 3.5 shows the construction of a 7.62mm calibre NATO ball round and the ballistically matched tracer round.

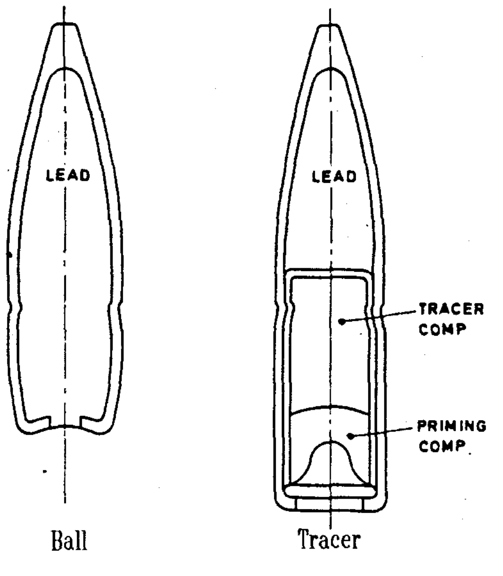


Fig 3.5 7.62mm NATO Ball and Tracer Bullets.

It can be seen from Fig 3.5 that the tracer bullet is longer than the ball round and the tracer compound also makes it lighter. The heavy lead core at the front of the bullet moves the centre of gravity forward. Consequently the tracer round is less stable than the ball round. The barrel twist rate is often

determined by the need to stabilise the tracer round rather than the ball round. It is not possible to obtain a true ballistic match between the tracer and ball rounds because of the large constructional differences between them. Additionally, the tracer round loses mass as the tracer burns away in flight. However, the gas generated does produce a form of base bleed which increases the pressure at the back of the bullet and thus reduces the effect of aerodynamic drag, but the effect is small. The rounds are matched at a single typical operating range, which for the 7.62mm calibre rounds is less than 400m.

Traditionally the ball round has always been lead cored with a full metal jacket. However, Eastern European countries have for many years used soft steel cores to reduce manufacturing costs. The 0.5in calibre Browning heavy machine gun has also always had a soft steel core fitted to the ball round. In recent years the small calibre high velocity assault rifle ball rounds have also been fitted with a steel core to increase penetration performance against hard targets. Fig 3.6 shows the construction of the 5.56mm calibre NATO ball round and the 5.45mm calibre AK74 ball round.

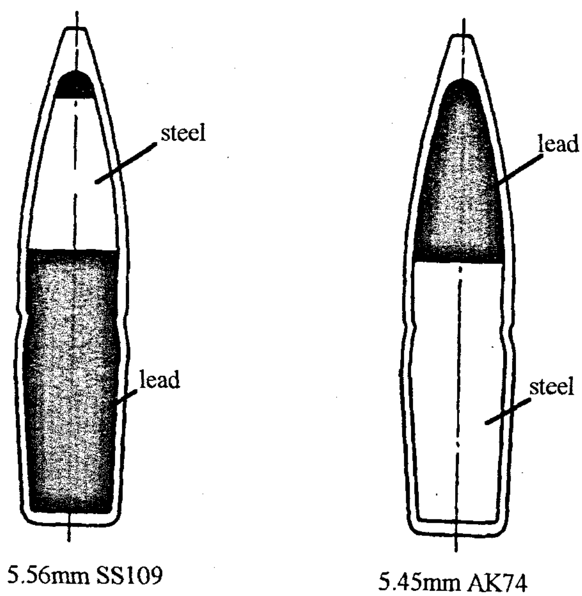
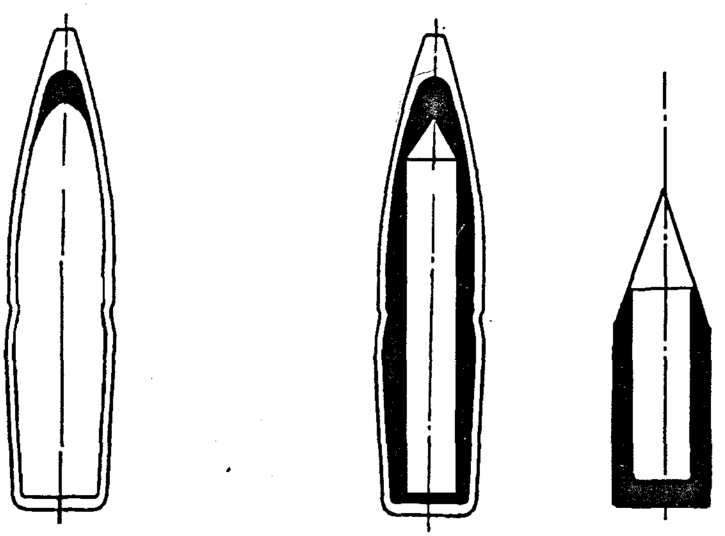


Fig 3.6 5.56mm SS109 Bullet and 5.45mm AK74 Bullet.

Armour Piercing Rounds

Modern targets are being fitted with ever increasing levels of armour protection. Special armour piercing bullets have been developed to defeat

these targets as shown in Fig 3.7. The simplest form of armour piercing bullet is fitted with a hardened steel core in place of the lead or soft steel core. Although steel has a lower specific gravity than that of lead, it has a greater armour penetration performance because when it hits the target the jacket is stripped off and it is the core only, with a relatively high sectional density, that passes into the target. The hard steel core does not significantly deform and so retains its high sectional density. The filler material in the nose of the bullet may be incendiary material so that when the bullet strikes a hard target the strike can be seen and it may set fire to any combustible material. Further armour penetration can be obtained by using a tungsten core. Tungsten has a high specific gravity (17) compared to that of steel (7.8) and is also very hard so that the armour penetration is also high. This approach has been taken to the extreme by the development of Sabotted Light Armour Penetrator (SLAP) rounds which use sub-calibre tungsten cores which are fired at very high velocities, usually in excess of 1200m/s. These very high velocities can only be achieved by making the total projectile mass (core and sabot) lighter than the standard ball round if the maximum allowable chamber pressures are not to be exceeded. However, rounds with tungsten penetrators are two or three times as expensive as conventional ball rounds and so are therefore usually restricted to use during special operations.



a b c

Fig 3.7 Armour Piercing Bullets.

a. Steel cored.
b. Tungsten cored armour piercing round.
c. Sabotted light armour penetrator.

Duplex Rounds

To increase the probability of hitting the target, the duplex round shown in Fig 3.8 was developed. This consists of two bullets in tandem. The second bullet has an angled base that gives it a degree of random dispersion. The Americans used a 7.62mm calibre version in Vietnam that produced a dispersion of 75cm at 200m and gave it a claimed increase in hit probability of between 25-75%. This type of round has not been developed in the small assault rifle calibre of 5.56mm because the weight of each bullet would be too low for it to cause sufficient damage.

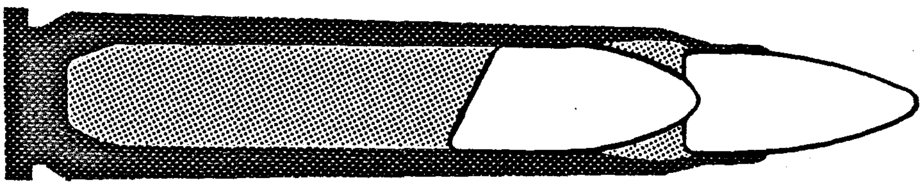


Fig 3.8 Diagrammatic Cross-Section of a Duplex Round.

Flechettes

Fin stabilised projectiles, known as flechettes, were developed to be fired as multi-projectiles from large calibre weapons. Sectional density (mass per unit area) of these projectiles is high so that velocity loss with range is low and armour penetration is high: they are particularly penetrative against modern body armour. Fin stabilised projectiles, such as flechettes, are normally fired from a smooth bored barrel with a sabot because high rates of spin create high angles of yaw which are detrimental to performance. Fig 3.9 shows a single flechette round developed for a smooth bored 5.56mm calibre assault rifle.

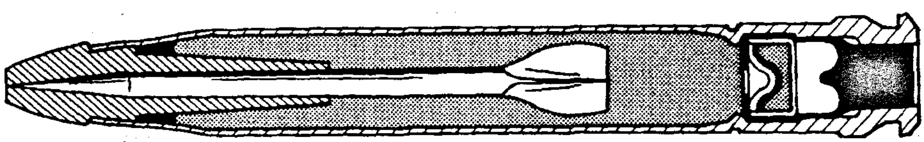


Fig 3.9 Cross-Section of an Assault Rifle Flechette Round.

The major disadvantages associated with flechettes are that they usually have unacceptably large angles of dispersion and they have low levels of lethality, cost more and are the same weight and size as a conventional ball round. These characteristics are responsible for only small numbers of these types of projectile being developed in the smaller calibres and none are in service at the time of writing.

Shotguns

Shotguns have been used as military weapons for many years. They are smooth bored weapons that usually fire multiple projectiles and usually have only a short operating range. Fig 3.10 shows a cross-section through a shotgun cartridge loaded with small diameter shot. Large diameter shot is often used for military purposes. Single, drag stabilised projectiles (usually referred to as solid slugs) may also be fired. High explosive rounds have been developed and there are a variety of chemically filled projectiles for firing tear gas, rubber balls or wooden batons for anti-riot purposes. Rounds have also been developed for firing multiple flechettes.

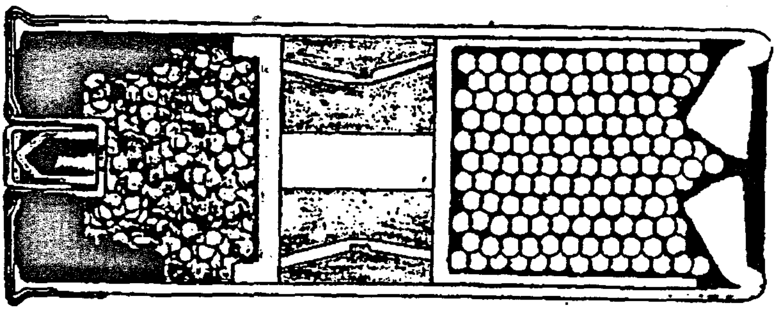


Fig 3.10 Typical Shotgun Cartridge

Case Telescoped Ammunition (CTA)

CTA has been developed in calibres from 5.56mm to 90mm. Fig 3.11 shows the cross-section through a typical CTA round. It has the same performance as a conventional round of the same calibre. It is much shorter than a conventional round with the projectile completely in the case and surrounded by the propellant. To provide sufficient space for the propellant, the cartridge case is made with a larger diameter than a conventional round. This design allows the breech of the weapon that fires CTA rounds to be much shorter than a weapon that fires conventional rounds, which can be significant where weapon size is important. They give the best results in the larger calibres.

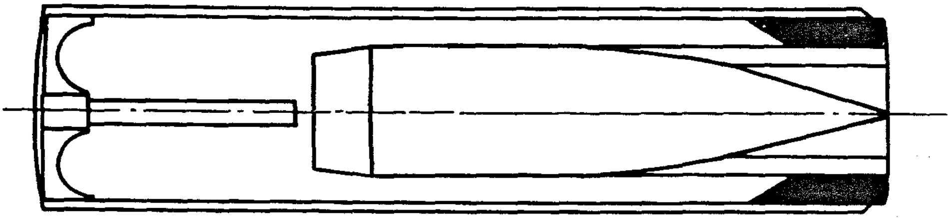


Fig 3.11 Cased Telescoped Round.

Training Rounds

Training rounds have been developed which have a shorter range than a conventional ball round. The bullet is much lighter and is often made of plastic. The velocity is also usually lower. Whilst this allows them to be used on smaller ranges than usual, it can create problems with weapon cycling. Frangible rounds have also been developed which disintegrate into dust on impact with a hard target. This avoids ricochet and splash back and so allows the rounds to be fired against hard targets during training. However, they can be just as lethal as a ball round if fired directly at an unprotected person, thus they allow lethal action in a dangerous environment, i.e. where penetration is highly undesirable.

Blank Rounds

Blank rounds are cartridges that do not fire a projectile, or may fire a very light projectile for a short distance. Their purpose is for use in training and ceremonial duties. They are often filled with a very fast burning propellant to achieve the required pressure build up in the cartridge with a low resistance to the expansion of the propellant gases. To enable the cartridge to be fed through the feed system of a gun, the outside shape of the cartridge usually resembles a conventional ball round. For blank rounds made by crimping the end of a conventional cartridge case, it is usually necessary to modify the feed system and provide the weapon with a blank firing attachment to enable it to cycle.

Ballastite Cartridges

These are cartridges similar to blank rounds but filled with ballastite which develops much higher chamber pressures than conventional propellants. They are used for such applications as firing muzzle launched grenades or line throwing where higher muzzle pressures are required.

Drill Rounds

Drill rounds are used by armourers in the workshop for checking weapon function and by soldiers for practising weapon drills. They are usually made with a silver coloured cartridge case often with flutes or prominent holes drilled through for easy identification. A primer is not fitted and the empty primer pocket may be filled with plasticine to check firing pin protrusion.

Proof Rounds

Before a weapon is released for use after manufacture, it is subjected to a proof procedure. One of the requirements is to fire an over pressure round to ensure that no errors have occurred during the manufacturing process and that the weapon is capable of withstanding the firing forces imposed upon it. A

standard ball round is specially loaded to give an over pressure of 30% greater than the standard ball round. Two of these rounds are usually fired through automatic weapons: the first has all traces of lubricant removed from the chamber and the cartridge case so that it grips the chamber and generates maximum pressure. The second round is lightly oiled so that maximum force is applied to the locking system. For certain calibres, particularly the 5.56mm calibre round, it is difficult to load sufficient propellant into the case to produce the 30% over pressure required. Special energetic propellants must be used to overcome this problem, and often the ammunition has to be heated to raise the pressure to the necessary level.

Propellants

Modern small arm propellants can be either single based or double based. Single based propellants consist of nitro-cellulose only. Double based propellants consist of a mixture of nitro-cellulose and nitro-glycerine. In the UK double based propellant is used in 5.56mm calibre ammunition and single based propellant is used in 7.62mm calibre ammunition. Double based propellants burn at a higher temperature than single based propellants resulting in higher rates of barrel wear. However, double based propellants have a higher energy per unit mass so that an improved performance can be achieved for the same cartridge case volume. In the UK most small arms propellants used at present are cut tubular whilst almost all other nations us ball propellant. Ball propellants are usually simpler and cheaper to manufacture but it is more difficult to exercise control over their burning properties.

Caseless Ammunition

In this type of ammunition the propellant is bonded to the bullet and obturation of the breech is achieved mechanically by the gun. Having no cartridge case, the ammunition is lighter and uses fewer raw materials. This type of ammunition has been under development for many years in Germany. Development has been plagued by problems including:

- Location of the initiating cap and its extraction or complete combustion.
- Achieving consistent internal ballistics.
- Strength of the round during handling, magazine loading and chambering.
- Resistance of the propellant to chemicals (solvents etc.) during handling, and its sensitivity to accidental ignition.
- Tendency of chambered rounds to cook-off in a hot gun.
- Extraction problems if there is a misfire.

Almost all of these problems were overcome or minimised by Dynamit Nobel in the development of the Heckler and Kock G11 4.7mm calibre caseless assault rifle. It had reached the stage where it could have been introduced into the German army but the programme was cut for economic reasons and the inherent disadvantages of the caseless system.

Cartridge Identification

There are a number of parameters that define a round of ammunition. First the calibre, secondly the length of the cartridge case and thirdly the rim type if there is any likelihood of confusion. This may not be sufficient, since ammunition may be of the same dimensions externally, but of a different make up internally (e.g. 5.56x45mm). Further information may be needed to completely define the ammunition. In the above case it would either be the SS109 NATO or the US M193 type designation.

To enable even further identification of the type of round in the field it is usual to use a colour code system by painting the tip of the bullet. The UK system is as follows:

5.56mm calibre

Ball	Plain or green tip
Tracer	Red or brown tip
Armour piercing	Black tip
Practice	Blue tip
High pressure	Silver case

7.62mm calibre

Ball	Plain
Tracer	Red or orange tip
Armour piercing	Black tip
Frangible	Green tip with white ring
High pressure	Silver case

12.7mm calibre Browning

Ball	Plain
Tracer	Red, orange or brown tip
Incendiary	Blue tip
High pressure	Silver case
Armour piercing	Black tip
Armour piercing incendiary	Silver tip
Armour piercing incendiary tracer	Red tip with silver ring
Spotter tracer	Red tip with yellow ring or yellow tip with red ring

Ammunition Performance

Tests have been carried out against the new CRISAT protective vest and show that, even at point blank range, the 9mm NATO ball round when fired from a 150mm sub-machine gun barrel will not penetrate the protective vest. Table 3.1 shows the ranges at which small arms bullets will penetrate the vest when fired from long barrelled weapons (maximum muzzle velocity).

Table 3.1 Ranges at which different bullets will just not penetrate CRISAT CBA.

Bullet	Range (m)
7.62mm NATO ball	600
7.62mm NATO AP	>1000
5.56mm NATO ball	570
7.62mm AK47	480
5.45mm AK74	420
5.7mm SS190	120

The ranges given in Table 3.1 are those for which the CRISAT - defined body armour gives complete protection. The lethal range will be somewhat less.

Modern armies are highly mechanised and many potential targets will therefore be inside vehicles that will give added protection. The NATO CRISAT document (TA1) gives a definition of the protection given by light and medium trucks as well as APCs, IFVs, attack helicopters and some field fortifications. It also gives the ranges at which protected and unprotected personnel in these vehicles are incapacitated for 5.56mm, 7.62mm and 12.7mm calibre rounds. This indicates it is only the 12.7mm weapon that is capable of incapacitating protected personnel inside most military vehicles at anything other than very close range.

Effect of Range

When a bullet leaves the barrel of a gun it will have a certain velocity which will be the maximum value throughout its trajectory. The velocity will decrease with range due to the friction of the air through which it is passing. Fig 3.12 shows the typical curves of velocity with range for 5.56mm, 7.62mm and 12.7mm ball rounds.

When a bullet leaves the barrel of the gun it will start to fall to earth. When fired parallel to the earth it will hit the ground at approximately the same time as the empty cartridge case that is automatically ejected from the weapon. At short ranges and for high velocity bullets, the distance that the bullet falls is small and is usually ignored. At longer ranges the effect becomes significant and should be compensated for by firing above the target. Fig 3.13 shows the amount that the bullet falls with range for 5.56mm, 7.62mm and 12.7mm ball rounds.

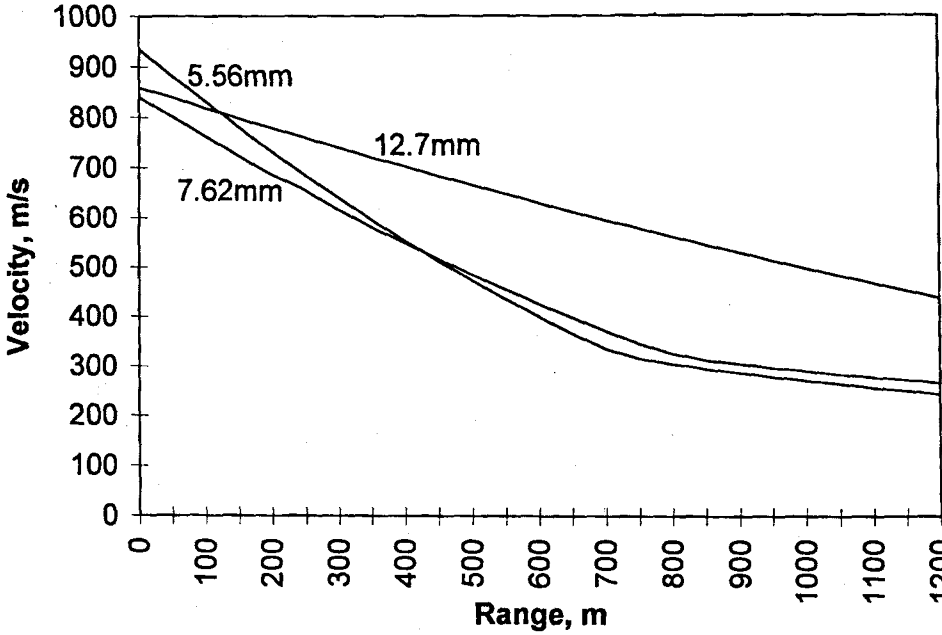


Fig 3.12 Velocity v Range for 5.56mm, 7.62mm and 12.7mm Ball Rounds.

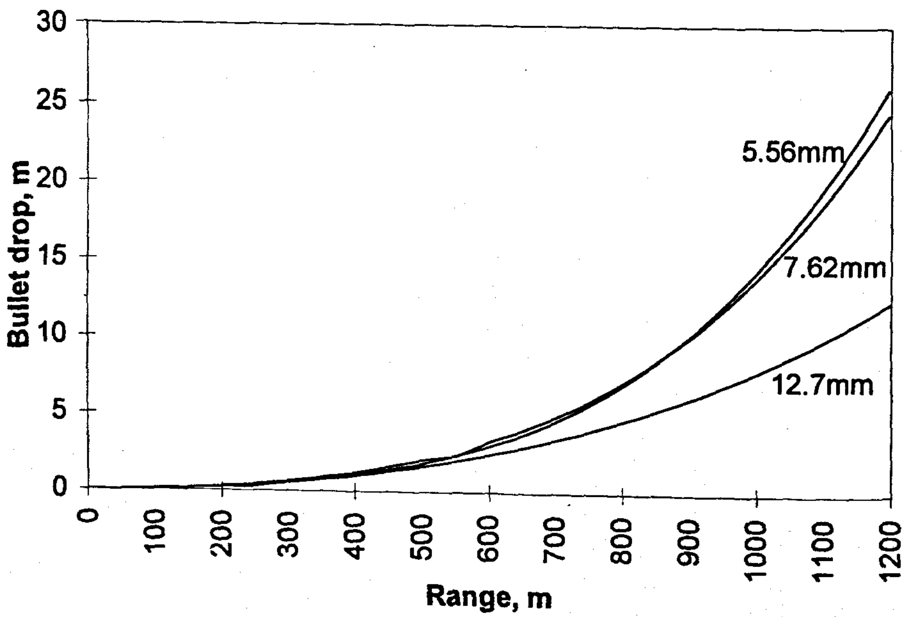


Fig 3.13 Fall of Bullet with Range for 5.56mm, 7.62mm and 12.7mm Ball Rounds.

4. Barrels

Purpose

(The purpose of the barrel is to impart velocity and direction to the bullet.) It must withstand the high pressures and temperatures that are developed each time the weapon is fired. The rear of the barrel locates the cartridge and the front part is used for the expansion of propellant gases that impart velocity to the bullet. In rifled weapons the barrel also imparts spin to the bullet by using helical grooves machined into the bore. The main dimension of a barrel is its calibre which is the dimension of the bore before the rifling grooves are machined. Barrel length is an important parameter because it affects the muzzle velocity of the bullet: the longer the barrel, the higher the muzzle velocity.

Barrel Construction

The barrel comprises an independent block, referred to as the barrel group, which consists of the following parts:

- Barrel.
- Receiver.
- Barrel supports.
- Barrel attachments.

The barrel is fitted into the receiver, which closes the barrel bore from the end of the cartridge chamber and serves to position the bolt, to which the firing loads are transferred. For automatic weapons the barrel breech is formed by the closing bolt, or breech block, which is connected to the receiver when firing. Thus, the receiver supports the bolt and transfers the force of the propellant gases to it. Barrel supports serve to mount and locate the barrel in the weapon. The mounting may be either fixed or a sliding design. For small calibre weapons the mounting is fixed and the supports serve to hold and support the weapon. Barrel attachments consist of a variety of components, the most important being:

- Muzzle brakes.
- Recoil increasers.
- Flash hiders.
- Noise suppressors (silencers).
- Muzzle deflectors.
- Gas blocks (gas operated weapons only).

Barrel Types

Small arms are fitted with either monobloc or compound barrels. Monobloc barrels are made of one piece of material whilst composite barrels consist of a monobloc barrel with an insert fitted to protect the breech end from wear. The barrel has a major effect on the construction of the whole weapon. The basic requirements are:

- Required strength at maximum operating load.
- High rigidity to minimise vibrations.
- Maximum straightness.
- Concentricity between inner and outer diameters.
- Adequate service life.
- Optimum mass for strength and stiffness.
- Low manufacturing costs.

Barrel Bore

The barrel bore is the internal part of the barrel with a tapered opening at the breech to house the cartridge and to guide the bullet during firing. The bore has the following parts as illustrated in Fig 4.1:

- Breech.
- Cartridge chamber.
- Forcing cone.
- Rifled section.

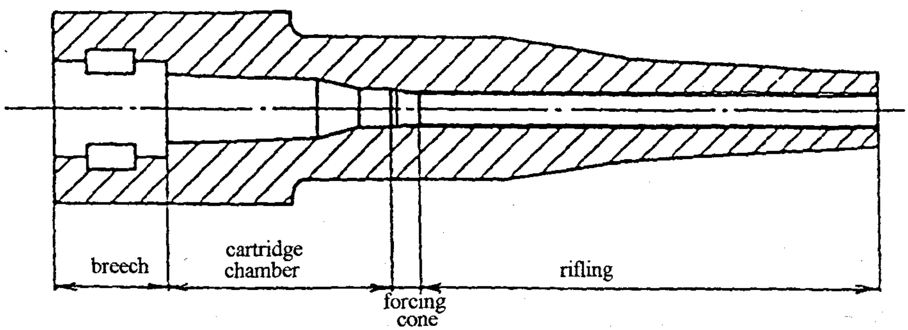


Fig 4.1 Basic Parts of the Barrel Bore.

The barrel bore is symmetrical about the longitudinal axis and diminishes in diameter towards the forcing cone. The rifled section is usually parallel.

Cartridge Chamber

The cartridge chamber serves to house the cartridge in the barrel. The cartridge case seals the rear end of the barrel and prevents the propellant gases leaking from the breech end when the weapon is fired. The layout and shape

of the cartridge chamber depends upon the design of cartridge. Each part of the cartridge chamber follows the shape of the cartridge case. However, radial and axial dimensions of the cartridge case differ from that of the chamber by the amount of clearance between them as shown in Fig 4.2

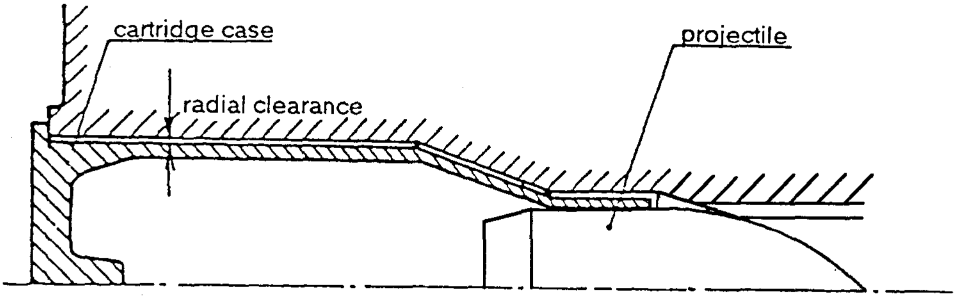


Fig 4.2 Clearance between Case and Chamber.

The longitudinal shape of the cartridge case is designed for easy loading and extraction of the cartridge case after firing. The cartridge case and chamber are conical in shape with clearance between the chamber and the cartridge. For a rimmed round, positioning is achieved by squeezing the cartridge case rim between the barrel and the breech as shown in Fig 4.3. A disadvantage with rimmed rounds is that the protruding rim causes weapon feed problems. Also, when the breech block closes there is a hard impact against the barrel. For rimless cartridges there is a longer distance between the breech block and the seating point as shown in Fig 4.4. Rimless cartridges cause the fewest feed problems; consequently this is the most widely used design for cases. An additional advantage of rimless cases is that the impact by the breech block is reduced when it closes.

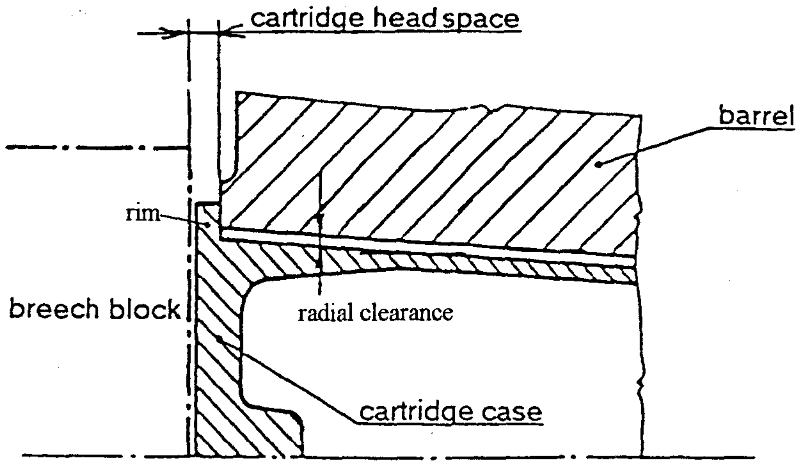


Fig 4.3 Positioning of a Rimmed Round in the Chamber

The accuracy of the weapon is considerably affected by the muzzle of the barrel which affects the flow of propellant gases around the bullet as it leaves the barrel. It is essential that the end of the muzzle is perpendicular to the barrel axis. The internal edge of the muzzle is usually rounded with a greater radius than the groove depth. For barrels requiring maximum accuracy, such as sniper rifles, the muzzle end is counter bored several calibres in depth, which results in a cylindrical cavity of a diameter which is greater than the diameter of the bullet. This provides constant gas flow around the bullet as it leaves the muzzle.

Barrel Mounting and Guides

The barrel is attached to the weapon by the breech end to the breech casing and barrel supports. In weapons with fixed barrels, the receiver group and the weapon casing are the same and one of the main parts of the weapon. On weapons with a recoiling barrel the barrel is attached to the receiver group which locates the barrel in the weapon casing. The breech block and bolt recoils together with the barrel in the breech casing. The receiver group has at least one guide, usually to the rear as shown in Fig 4.7.

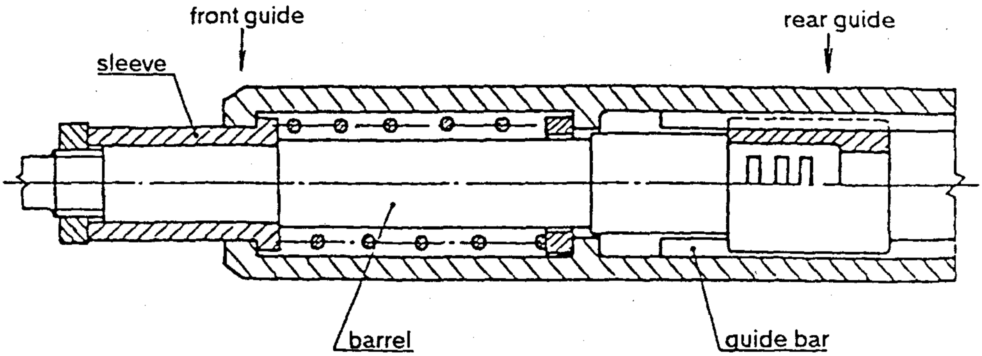


Fig 4.7 Typical Barrel Arrangement for a Recoil Operated Weapon.

The front guide is positioned directly on the barrel. The torque acting on the barrel caused by the bullet spin is resisted by the receiver group guide or by a special guide bar which meshes with the breech casing recess. The barrel may be fixed or have a quick change facility. Fixed barrels are usually attached to the weapon by a screw thread on the outside of the breech end of the barrel.

Barrels of machine guns with a high rate of fire can become excessively hot. Usually there is a facility to change the barrel for a cold one on the battle field. The method of attaching quick change barrels to the weapon can be of the following design:

- Cotter joint.
- Ribbed joint (bayonet joint with straight ribs).
- Interrupted thread.

The quick change joint is usually referred to as the barrel nut. A cross wedge bears against a lug on the barrel or it passes through the cross groove on the barrel as shown in Fig 4.8. The bevel of the cross wedge presses the barrel into the receiver group. It is locked in position by means of a nut or spring-loaded pin.

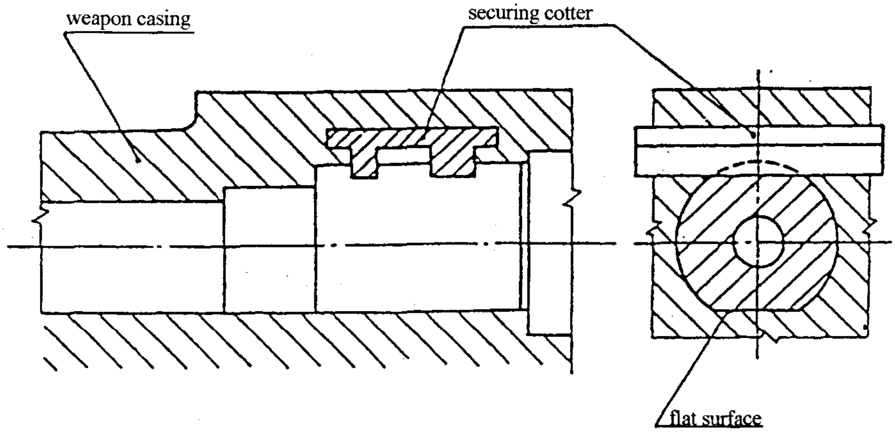


Fig 4.8 Cotter Joint for a Quick Change Barrel.

The ribbed joint has both ribbed and smooth sectors along the barrel circumference and the barrel beds into the breech casing as shown in Fig 4.9.

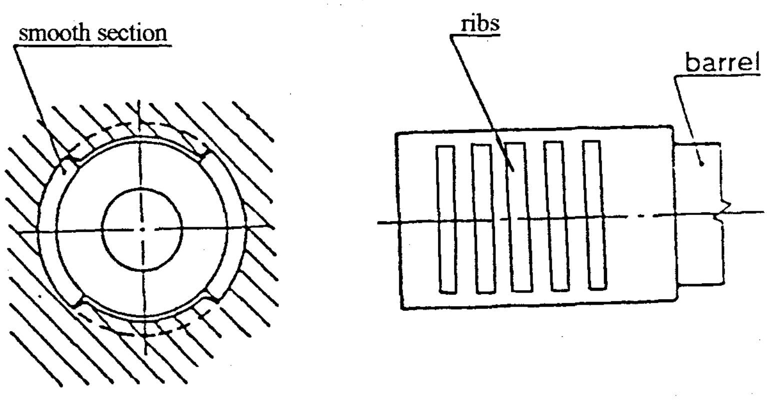


Fig 4.9 Ribbed Joint for a Quick Change Barrel.

The ribbed and smooth sectors are usually between two and four in number. One sector has several cross ribs with a rectangular profile. The interrupted thread joint is identical in design except the ribs are in the form of a thread. This design makes it possible to press the barrel towards the breech block. To join the barrel to the breech casing, the barrel is placed with its threaded sectors into smooth sectors of the breech casing and rotated to lock the two together. To provide for precise positioning of the barrel, the receiver group is equipped with supports in the form of spigots before and after the joint. A ratchet is usually provided to prevent the barrel from working loose.

Barrel Heating

This topic is covered in "The Introduction to Operating Mechanisms" Chapter 5.

Barrel Wear

When a gun is fired, a complex set of conditions occur in the barrel that mechanically and thermally stress the bore which eventually lead to the barrel wearing. Barrel wear reduces weapon performance and once performance falls below the required level it is replaced. The service life of a barrel is usually set by the number of rounds it has fired. The condemnation criteria for barrels is set by:

- Reduction in muzzle velocity
- Increase in dispersion
- Onset of bullet instability
- The weapon becomes a danger to the user

A common cause of barrel failure is by an obstruction, the most common of which are cleaning rods or cleaning materials. Mud or snow in the barrel can also form an obstruction. The common effect of firing a gun with an obstruction in the barrel is to cause the barrel to burst. Another possible cause of catastrophic barrel failure is that of fatigue. This is a highly unlikely mode of failure mechanism in modern military small arms, although it has been known to occur in weapons produced under war time conditions where the quality control of the barrel materials was not as stringent as in peace time conditions.

Barrel wear is usually greatest in the rifling lead because of the impact of the bullet onto the forcing cone. Chemical reactions between the burning propellant and the surface of the barrel produce cementation and nitration of the surface in the form of a layer 0.05-0.1mm thick. Erosion of the bore by the propellant gases appears as a washing away of the bore surface. Erosion effects increase as the bore becomes hotter. The hottest part, the forcing cone, is particularly exposed to erosion effects. Wear causes the forcing cone to move forwards in the bore which results in greater bullet insertion depth and a

resultant reduction in the muzzle velocity of the bullet. The burning propellant has several effects on barrel wear. It causes a high thermal gradient at the surface of the barrel; this leads to high thermal stresses that result in a network of cracks on the bore surface, and forms the basis of mechanical wear and erosion. Also, heating of the barrel results in a decrease in material strength that leads to lower resistance to erosion and abrasion. The cyclic character of heating and cooling of the surface layer can lead to mechanical and thermal fatigue resulting in the development of cracks and a reduction in the resistance to wear. Wear is not distributed uniformly along the barrel. The most critical region of wear is the forcing cone and beginning of rifling up to about the point of maximum pressure. Maximum wear is usually at the beginning of the full depth of the grooves. There follows a region of medium wear that lies near the point of maximum pressure. In the middle part of the bore, the wear is small and uniform.

Hard chromium plating of the bore, with a plating thickness up to 0.05mm is commonly used on small arms. This can double the barrel life when the weapon is fired under the most severe firing cycles. Stellite liners are fitted to the breech end of the barrel in certain sustained fire medium machine guns and considerably increase the barrel life of these weapons.

5. Introduction to Operating Mechanisms

General

Small arms can either be powered internally, with the source of energy provided by the propellant, or externally by an electric motor or hand cranking.

A small arm is, in effect, a single cylinder internal combustion engine, of which the bullets form a series of expendable pistons that are thrown out of the barrel (or cylinder). The propellant gases are also expelled from the muzzle, some of them at considerably greater velocity than the bullet itself. The greater the proportion of charge mass to bullet mass in a round, the greater is the significance of the propellant gases in the momentum balance of the weapon system.

Distribution of Energy

As has been indicated already, the means whereby the energy of a small arm round is distributed can vary considerably. However, some items can fairly easily be quantified, using the normal laws of mechanics and thermodynamics. These are:

- A bullet can be weighed, its muzzle velocity measured and its forward kinetic energy calculated. Spun bullets also have rotational energy, but this is usually negligible.

- Heat is transferred to the barrel from the high temperature propellant gases and by the friction of the bullet passing up the bore. The total heat loss can be calculated, based on the mass of the barrel and other heat affected parts, their specific heats and on the temperature rise.

- Recoil energy can be determined by using a ballistic pendulum, on which the weapon can be freely suspended. The height to which it swings when a round is fired is proportional to the free recoil energy of the weapon.

- The input of energy from each round depends on the mass of propellant burnt, in grams, and its specific energy, in Joules per gram.

- The energy imparted to the muzzle gases as blast and heat cannot be directly measured. However, as this represents the balance of the energy losses from the system, it follows that:

Muzzle Gas Energy = Propellant Energy Input - (Bullet Energy+Barrel Heat +Recoil Energy)

As a very approximate guide, the distribution of propellant energy for a small arm can be taken as:

Kinetic Energy of Bullet	30%
Heat to Barrel, etc	30%
Muzzle Gas Energy	nearly 40%
Recoil Energy	0.1%

The very small proportion of the whole that becomes evident as Recoil Energy is noteworthy.

Efficiency

The efficiency of a small arm is expressed as:

$$\frac{\text{Bullet Muzzle Energy x 100\%}}{\text{Propellant Energy}}$$

This usually gives, for high velocity weapons, approximately 30% efficiency which compares poorly with the output of petrol engines (35%), diesel engines (38%) and power stations (40+%).

The Operating Cycle

Regardless of whether a small arm is manually operated, self loading or automatic, in general, a number of functions must occur for each round and these constitute the cycle of operations:

- A round must be fed, normally from a magazine or belt.
- The round is chambered.
- A firing mechanism is cocked.
- The breech is locked.
- The round is fired by the firing mechanism.
- The breech is unlocked.
- The breech is retracted, the return spring compressed and the empty case extracted.

- The empty case is ejected.

Variations in the Cycle

The basic cycle can be modified, after due thought, to suit particular needs. As examples, some blow back weapons are never locked, but rely on either the inertia of a heavy bolt, or on intentional mechanical disadvantage, to keep the breech closed whilst pressures are high. For a weapon firing caseless ammunition, there should be no need to extract or eject an empty case, although provision would need to be made for misfires or unloading.

Locking

Rounds fired in small arms generate very high pressures for very short times. Such pressures, if uncontrolled, could either damage the weapon, or the firer. Therefore it is normal to design into a weapon a means whereby the bolt, or breech block, can be held against the chamber end of the barrel before the pressure becomes dangerously high and removed immediately it has dropped to a safe low level. The most common forms of locking are achieved either with devices that tilt, go past-top-dead-centre, have locking lugs, or rotate serrated bolts. Once such a device is "locked" no amount of pushing on the bolt head will open it.

Pressure and Time

In a self-loading gun obtaining its power from the pressure developed by the burning propellant, the duration of time when this power can be safely tapped is limited. A curve plotting the pressure in the bore against time for a typical small arm is shown in Fig 5.1.

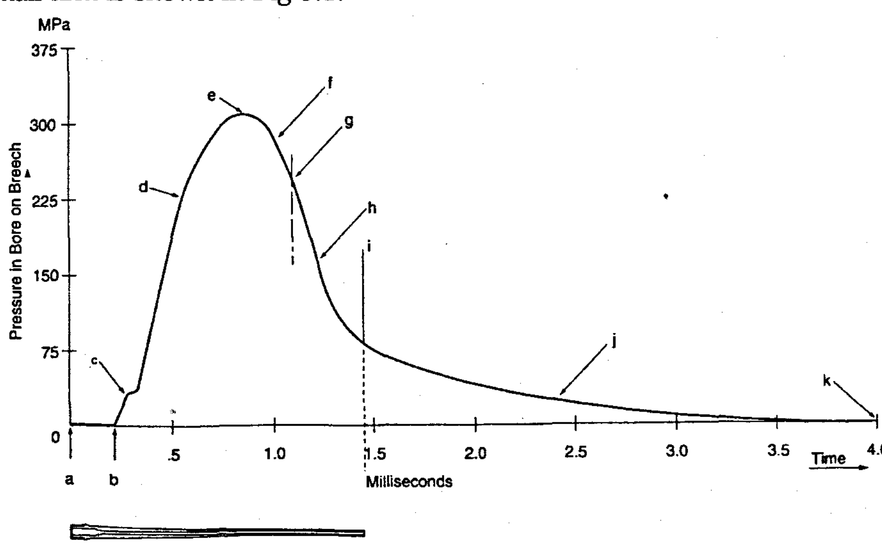


Fig 5.1 Pressure/Time Curve

Sequence of Events

The sequence of events, as shown in Fig. 5.1 is:

a. The striker hits the cartridge cap.

b. There is a delay before the ignition sequence starts. A tiny quantity of highly sensitive explosive detonates to produce a flame, which ignites the outer surface of the propellant.

c. Pressure rises inside the cartridge case until it is sufficient to blow the bullet out of the mouth of the cartridge. Considerable resistance is encountered as the bullet engraves in the rifling. This occurs approximately 0.3ms after cap strike.

d. The propellant produces gas faster than the volume behind the bullet increases and therefore the pressure rises rapidly.

e. At this point the highest pressure is reached.

f. The velocity of the bullet is now so great that the increase in volume behind the bullet is growing faster than the propellant can fill it and so the pressure now drops.

g. The propellant is all burnt.

h. The bore behind the bullet remains full of hot gas that expands adiabatically.

i. The bullet emerges from the muzzle, and some of the gases overtake it. Pressure in the bore remains relatively high. Although the bullet is moving in the bore of the rifle for only just over one millisecond, it may reach a velocity of 1,000m/s at the muzzle. Maximum accelerations are of the order of 1,500,000m/sec^2, so the set back forces are enormous, sufficient to distort a lead-filled bullet to fill any cavities in the bore.

j. For a further 2 or 3ms pressure continues to drop in the bore. Only at this stage would it be safe to unlock the bolt of the weapon so that advantage could be taken of the blow back pressure remaining on the base of the cartridge.

k. The pressure in the bore drops to ambient. The entire duration from cap strike to this point is only about 4ms. Dead time follows before the next round is fired, with no pressure other than ambient in the bore. During this period, the working parts of the mechanism perform the operating cycle, using energy transferred to them whilst there was still pressure in the bore. This energy is in the form of kinetic energy that is used to push the

working parts of the weapon to the rear. At the same time energy is transferred to the return spring ready for it to push the working parts back to their forward position.

Obturation

Cartridge Case Obturation

Current conventional small arms all use cartridge cases to provide obturation at the breech end of the barrel until pressure has dropped to a safe low level. The part played by the case in the reliable working of an automatic weapon is shown in the much exaggerated sequence of diagrams in Fig 5.2. Although drawn, for demonstration, with a rimmed case, the reasoning that follows would equally apply to a rimless round:

- The cartridge is loaded into the breech, and the breech block closed. Because of manufacturing tolerances and possible temperature differences between gun and round, some clearance must be provided between the round and the chamber and between the round and the breech face. This is called "set back" or "cartridge headspace". The arrow depicts the striker hitting the cartridge cap, but before any pressure rise inside the cartridge.

- The propellant ignites, pressures rise to a low level (L). Until the bullet leaves the mouth of the case, (shot start), the cartridge does not move, but as the bullet moves into the rifling so the case pushes backwards against the breech face, thus increasing the clearance between the case and the chamber. With low pressure also in this clearance, thus on both sides of the case wall, there is no reason for the wall to move. Momentarily there may be a tiny pressure rise outside the breech, but it is insignificant, due to a very short duration.

- Pressure inside the cartridge case rises rapidly to a high (H) level, and the bullet starts to accelerate down the bore. Around the outside of the mouth of the case there is also high pressure so, apart from compression of the mouth, there is no tendency for movement. Down the outside of the case however, there is a pressure drop due to baffling in the constriction and when the pressure outside the case has dropped to a sufficiently low level, the differential between H and L is sufficient to bulge the case outwards against the chamber wall.

- Forward of the bulge in the case wall baffling becomes complete, and the case obturates forward towards the mouth, to form a complete seal between itself and the chamber wall. With a typical H of over 300 MPa (20 tons/in^2) the frictional force between the case and a dry chamber wall will be so great as to approximate "welding" the front end of the case to the

wall. If the breech block were removed before this "weld" was broken, the back of the case would be ripped off the front by the pressure on its base, and the separated case would cause a gun stoppage.

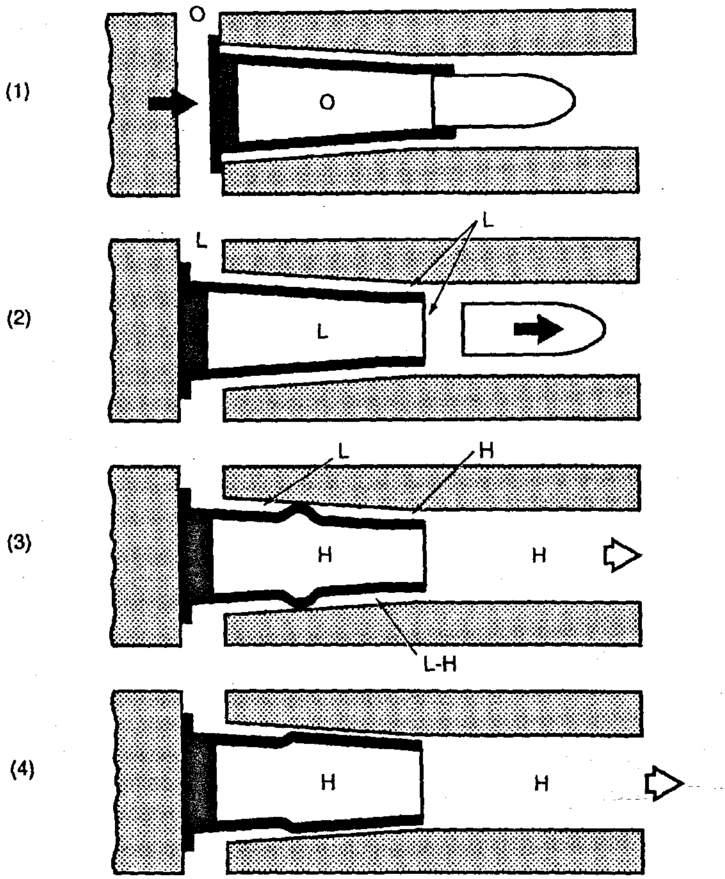


Fig 5.2 Sequence of Cartridge Case Obturation

The sequence just described varies in degree with the pressure of rounds and with the tightness of fit of the bullet in the case mouth. The higher the pressure of the round, the further forward it will obturate, which explains why very short stub cases are suitable for high pressure tank guns, but not for low charges in field artillery. If a field gun is fired with initially clean cartridge cases, it will be found that the outside of the cases remain clean when fired on high charge, indicating obturation near the case mouth, but are burnt black near the base of the cartridge when fired on the lower charges.

Other Methods of Obturation.

In another method of obturation the barrel and bolt are held together to give a good seal. However, such a system is very prone to wear and erosion and becomes rapidly unusable. In the case of rotating chambers such as Revolvers, Aden/Mauser aircraft cannon, and the German G11 caseless system, other methods need to be found to seal the gap between the bolt and barrel. In Figs 5.3.1a,b and c, the two mating surfaces are held together by the pressure provided by a ramp on the rear of the rotating chambers. This method can be used for increasingly powerful Revolver handguns, but is not sufficient for more high powered rounds or weapons with high rates of fire. Figs 5.3.2a and b can only be used on slow firing weapons, usually cannon. Such methods are not used today because of the need for a different form of ammunition and the long stroke movement needed. Fig 5.3.3 is the method used in the Aden/Mauser Aircraft Cannon with rates of fire between 1000 and 2000 rpm. It is also used in the H & K Caseless G11. The higher the pressure, the more the two surfaces are pressed together to give a good seal.

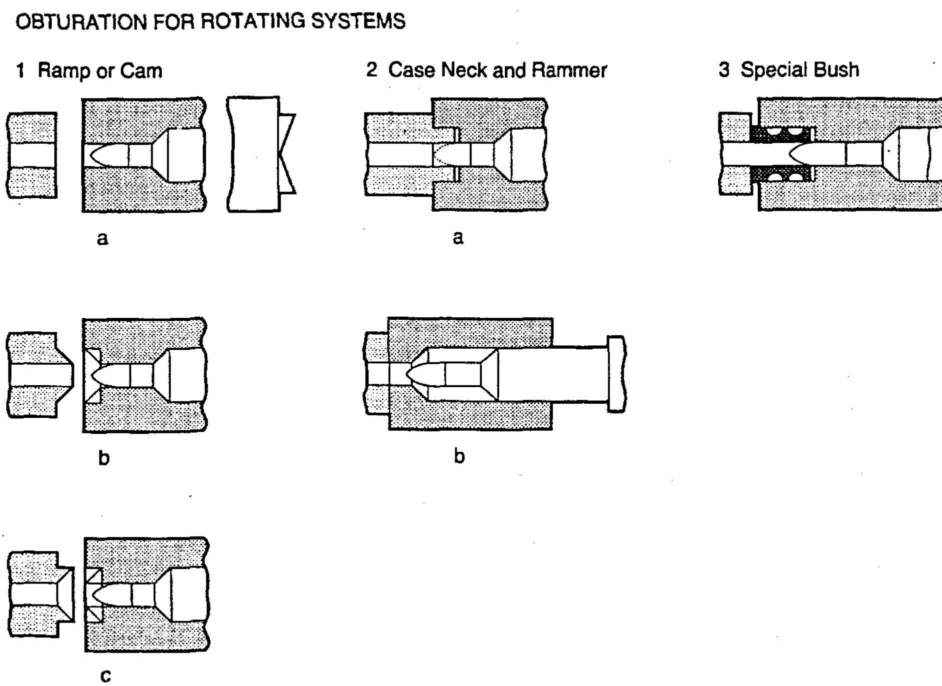


Fig 5.3 Rotating Chamber Obturation

Cartridge Headspace

Definition

The term "cartridge head space" has its major application to some aspects of

supporting the base of the cartridge in the chamber and the following definition covers the general case. Cartridge headspace (CHS) is the distance between the front face of the breech block and the seating surface of the cartridge case in the chamber. Note that this definition relates only to the weapon and is not a function of the ammunition fired.

Rimmed Rounds

In the rimmed rifle round, e.g the British .303 round, the seating face of the cartridge was the forward surface of the rim. Therefore the CHS was slightly greater than the thickness of the rim i.e. the distance between the bolt face and the chamber face when the breech block was locked. This was a dimension of about 0.064in. This is illustrated at Fig 5.4.

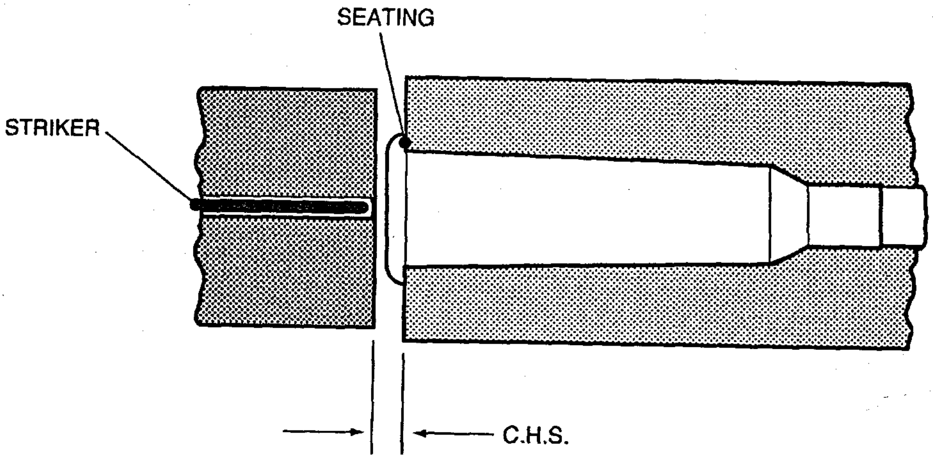


Fig 5.4 Cartridge Headspace for a Rimmed Round

Rimless Rounds

With the present, near universal use of the rimless round, the dimension of the CHS became a little more difficult to define precisely, because the cartridge now seats all along the small cone of the case. The CHS thus becomes the dimension between the front face of the breech block and a selected datum line on the small cone in the chamber (Fig. 5.5). In the L1A1 rifle this datum line is the centre of the small cone because that was the point selected by the Design Authority and this gives a CHS of 1.6325in.

In other weapons firing rimless rounds the datum point chosen was the rear edge of the small cone. For example in the case of the 7.92mm BESA MG the CHS was about 47.22mm. The Browning .3 MG is 1.94in. It is thus possible to have two rifles designed by different authorities, both firing the same round with the same chamber configuration but with different figures quoted for CHS

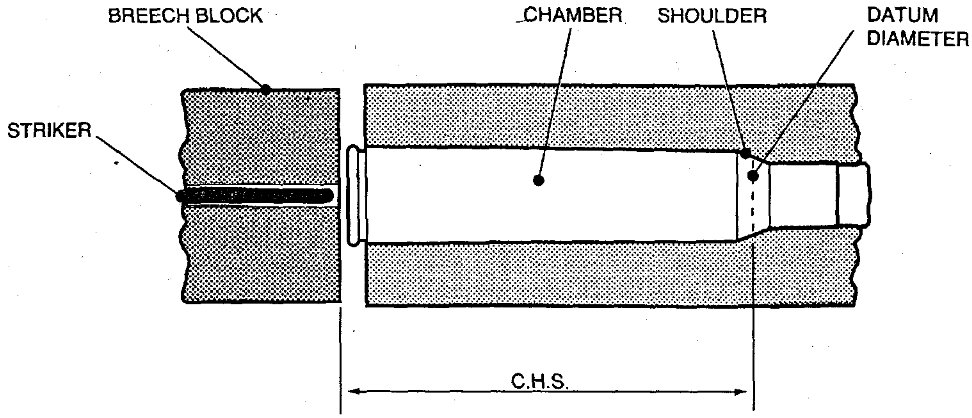


Fig 5.5 Cartridge Headspace for a Rimless Round

because different datum lines have been selected. In practice this does not present a problem because the armourer has "go" - "no-go" gauges for each weapon. If the breech locks on the "go" gauge the CHS is correct but it must not lock on the "no-go" gauge.

Problems

The CHS is important. If the CHS is too large the case may be damaged. In the worst event it will burst because it is unable to sustain the chamber pressure if it is not fully supported by the chamber and the face of the breech block. Excessive CHS will cause separated cases since on firing, the soft neck of the case will expand to grip the chamber wall and provide obturation whilst the harder and thicker rear part of the case will set back until it meets the breech face. Thus the case will be stretched and may well yield across its weakest section, which is at the start of the small cone. When the breech block is unlocked and withdrawn the major part of the case is extracted but the neck of the case remains in the chamber. Too small a CHS will cause a stoppage because the breech will be unable to close properly and the mechanical safety before firing will ensure that the cap is not initiated.

Adjustment

Until comparatively recently it has been almost universal in MMGs and very common in LMGs to provide a method of adjusting CHS. The method chosen varied with the methods of operation and of locking the weapon. For example, where the breech block locked into the body of the weapon using a tilting block or a lug device, the locking shoulder in the gun could be changed to correct the

CHS to allow for chamber wear. In some designs shims could be inserted to bring the breech block face further forward to correct excessive CHS. In another the barrel could be screwed back within the frame towards the breech block. Manufacturer's tolerances are catered for in final assembly by the use of a range of sizes of one component. Where no provision is made for adjustment of CHS the cheapest component is changed. For example the head of the bolt would be changed for a larger size to take-up excessive CHS. In modern designs wear is far less, due to the use of steels and alloys with better mechanical qualities and the gun itself probably wears out before CHS adjustment is necessary. Thus the correct CHS is "built into" the design and it is not possible to adjust it at all. If no adjustment is provided and wear occurs the gun will have to be returned for a factory repair.

Automatic Operation

The original expression "machine" gun dates back to the early days of weapon development when the source of power to carry out the cycle of operations was hand cranking. The weapon was then a machine in the true sense of the word. Modern weapons, with the exception of those that are externally powered, utilise energy derived from the burning of the propellant which otherwise would have been wasted. The sources of energy that can be tapped are recoil, muzzle blast and barrel gas pressure.

These sources of energy can produce three basic systems of automatic operation, which are known as:

- Blow back operation (sometimes called spent case projection).
- Recoil operation.
- Gas operation.

Operating Energy

These three methods, used to provide the automatic cycle of operation, mean ideally that only energy that would otherwise be wasted is used. In practice this is not completely true because, for a given round, a blow back operated weapon will generally have a reduced muzzle velocity compared to a gas or recoil operated gun. But also some energy may be lost in a gas operated gun and this could produce a slightly reduced muzzle velocity.

Distinction between the Propellant Methods

Care should be taken when discussing these operating methods because it can be seen that the boundary between the three methods is somewhat blurred. Both blow back and recoil operation depend entirely on the force produced by the gases acting through the base of the cartridge case against the front face of the breech block. It can also be argued that the cartridge case is a small piston

driven back by gas pressure and therefore all three forms of operation could be classified generically as "gas operation". Indeed all three methods use "blow back" to a greater or lesser extent due to there being some residual gas pressure in the barrel acting on the cartridge case when the breech is unlocked.

External Power

Unlike the above methods, no propellant power is used in this type of system. Instead some external force is used, normally either a person or an electric motor. There is nothing new about this method. The Americans Captain Gardner and Dr Gatling were the first to produce useful externally powered weapons in the 1870s. It is claimed that such a system should be inherently more reliable than one using propellant power and the greatest advantages are:

- Automatic clearance of stoppage due to failure of round to fire.
- Lack of toxic gases being introduced into a turret when used as a coaxial MG.
- Ability of system to have different rates of fire by varying the power supply (e.g. voltage to an electric motor).
- The design of such systems lend themselves to production by general engineering methods.
- Such systems are lighter and more compact because they do not need springs to store energy for returning the working parts to their forward position.

Bolt Operation

Closed Bolt

On loading, a round is placed in the chamber. It remains there until the firer decides to pull the trigger and discharge the round. After firing, the bolt is opened, the empty cartridge case is extracted and ejected. Immediately a new round is picked up by the bolt and chambered. It can then be fired, if the trigger is still pulled or the round can stay in the chamber, as required. Thus the normal state for a closed bolt weapon, once loaded, is to have a live round in the chamber. If a lot of rounds have been fired the chamber will be very hot. This heat will pass through the case, if used, and reach the propellant. Single base propellants will self ignite at around 190°C,while double base will go at some 150°C, thus causing a "cook off". A closed bolt is used with rifles where first round accuracy is required because there is no movement of a large, heavy bolt disturbing the aim of the firer.

Open Bolt

When the trigger is pulled in this instance, the bolt picks up a round, places it in the chamber, fires it and stays to the rear when firing stops. Thus the chamber is left empty until, and only when, a round is to be fired. This system is thus potentially not going to "cook off". However it is not consistent with a first round hit, because the movement of the bolt upsets the firer's aim.

Hybrid Systems

It is possible and would be useful, in a section weapon that was required to produce single round accuracy at one time and sustained fire at another, to have the bolt operation selectable. Indeed the German paratrooper's FG42 and an experimental model of the 4.85mm Enfield Weapon System (EWS) both had such a facility. The increased complexity and cost has made such a system unattractive previously, but might not be so much of an obstacle in the future.

Methods of Operation

The methods of operation are each described in more detail in the chapters that follow. Characteristics such as those listed above need to be understood before detailed requirements are agreed and the design, or selection, of a weapon system begins.

Heating and Cooling

Heating

There are two sources of heat, the hot propellant gases and friction between the bullet and the bore. This last source is difficult to quantify and is very small and thus can be ignored in this book. The flame temperature of a burning propellant is in the region of 2000°C. Heat is thus transferred to the bore during the time the propellant is present. The surface of the bore can reach up to 1000°C, but falls rapidly as the gases disperse. This heat is then conducted through the barrel wall and then to the atmosphere through convection and radiation. Unfortunately this loss is much smaller than the heat input and barrels rise in temperature rather quickly but cool only slowly.

The amount of heat transferred to the barrel depends upon the charge mass, the rate of propellant burning, and its flame temperature. It is also dependent on the barrel material, the area of the bore and the temperature differential between the gases and the bore. As firing continues, so the heat transfer becomes smaller, but the heat losses from the barrel become greater, so that ultimately a steady state is reached.

Although the heat input is greatest just forward of the chamber, where the barrel is usually thickest, most barrels taper towards the muzzle, and therefore

the temperature is unlikely to be uniform along their length. There will also be a temperature difference, even as much as 400°C to 100°C between the inner and outer surfaces of the barrel, varying from the chamber mouth to the muzzle. It can be seen from the graph in Fig. 5.6 that short breaks in firing reduce peak temperatures of the barrel internal surface although the bulk temperature increase of the barrel is little affected.

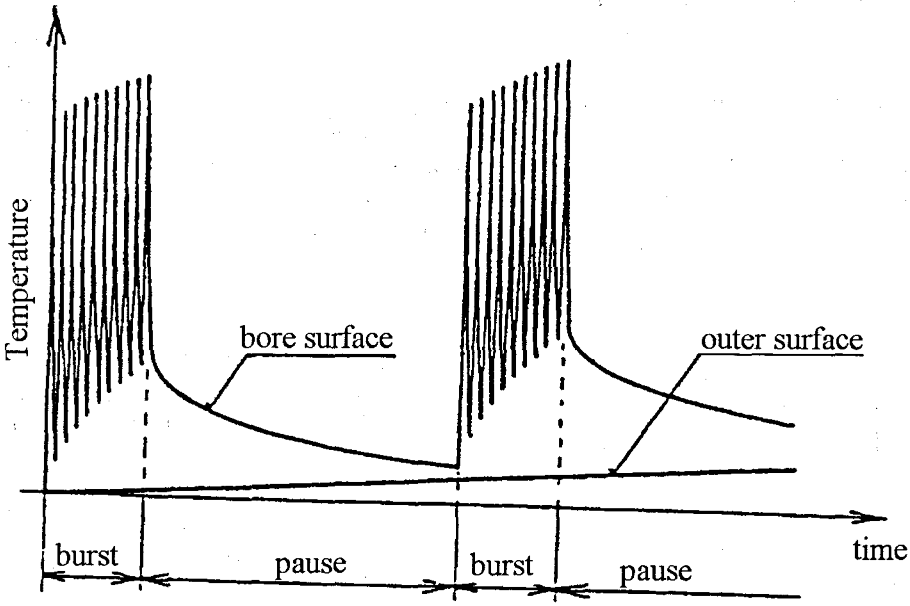


Fig 5.6 Barrel Heating at the Bore and Surface of a Barrel. (Bursts fired with a pause between them)

If a barrel temperature of 500°C is maintained, then permanent damage will be done to the barrel through accelerated wear and erosion.

Approximate Heat Energy Calculations

Work done by the gases = $P_M \dfrac{\pi d^2}{4} l$

where P_M = Mean Effective Pressure (= 60% of Max Pressure)
d = Bore Diameter
l = Shot Travel

Work done by the gases = $\eta \, m_C \, E_P$

where η = Thermal Efficiency (30% to 40%)
m_C = Charge Mass

E_P = Propellant Energy (3 to 4 MJ/kg)

$$\therefore \quad m_C = \frac{\pi \, P_M \, d^2 \, l}{4 \, \eta \, E_P}$$

Heating with a Single Barrel

If a large number of rounds are to be fired, the use of a single fixed barrel can be seen not to be sensible, from the graph below. After 20 minutes firing at 50 rounds per minute, the temperature has passed the critical point and any further firing will start to damage the barrel. During the SA 80 trials it was also found that firing between 300 and 360 rounds at any rate above 60 rounds per minute, heated the barrel so that a "cook off" was almost inevitable on ceasing fire with a round in the chamber, within 30s, or even quicker.

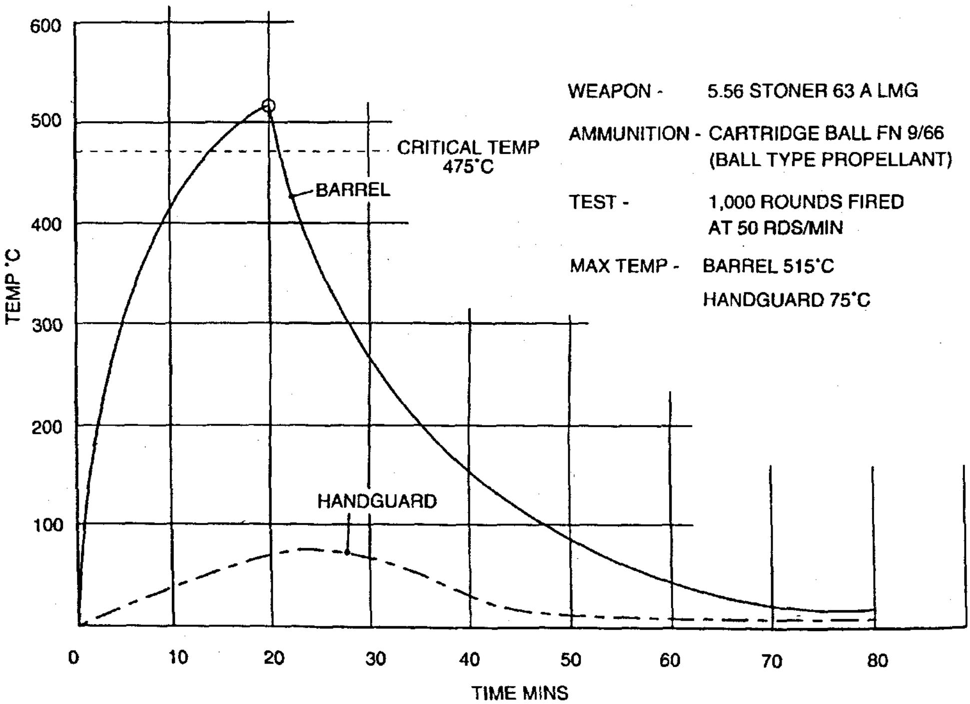


Fig 5.7 Heating for a Single Fixed Barrel

Barrel Changing

If a high sustained rate of fire is to be maintained with an air cooled barrel, then two or more changeable barrels are needed. Some form of forced cooling of the removed barrel is ideal, such as wet grass, a stream or a bucket of water. But

as can be seen in Fig. 5.8, even cooling in the ambient air is sufficient to allow a long period of fire at 50 rounds per minute.

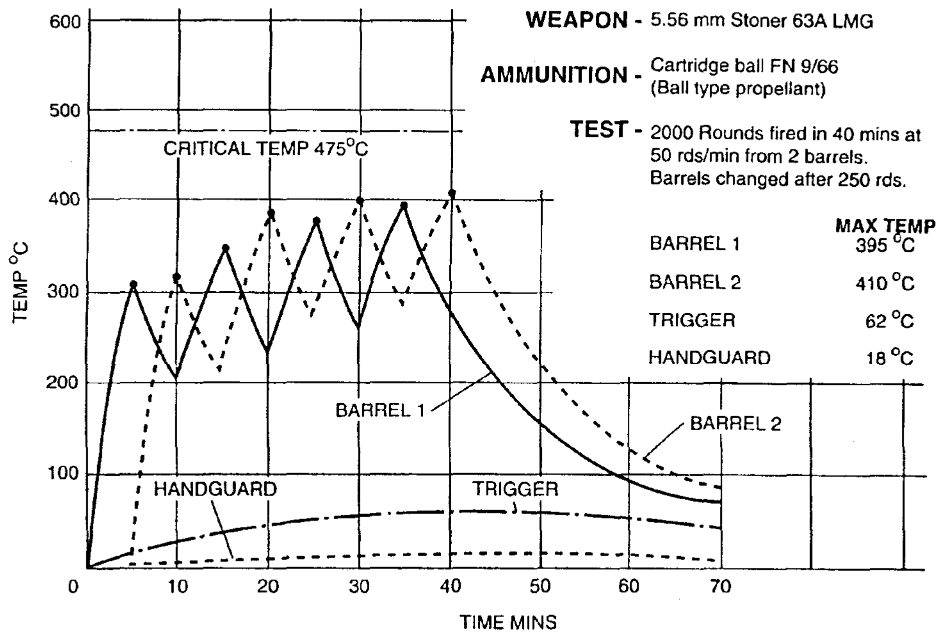


Fig 5.8 Heating with Two Changeable Barrels

Cooling

The prediction of cooling is a complicated process and involves differential equations. The heat from the propellant is conducted through the metal to the barrel outer surface. Theoretically, a thin barrel would get the heat from bore to outer surface most rapidly. However heat loss to the atmosphere is so slow that such a barrel would overheat very quickly and be impractical. But if the heat can be removed more efficiently, by using a liquid, then only ballistic strength is required in the barrel. This is used in the water cooled Vickers and similar weapons. For air cooled weapons then the barrel needs to act as a heat sink and therefore need to be thick. In small arms, if the barrel is capable of withstanding rough handling and bayonet fighting, then it should be a sufficiently good heat sink. The higher the sustained rate of fire, the thicker the barrel should be consistent with practical size and weight.

Convection

The rate of loss due to convection depends on the temperature difference, the surface area of the hot object and certain properties of the cooling medium.

Assuming a constant heat input, a constant barrel thickness, and a constant barrel temperature across the wall thickness, a simple estimate of the barrel temperature can be obtained from the following equations:

$$m\,c_v \frac{dT}{dt} = H\,A_i\,R - h\,A_o\,(T - T_a)$$

where

$$m = \rho \frac{\pi}{4} (D^2 - d^2)\,L$$

and $$A_i = \pi\,d\,L$$
$$A_0 = \pi\,D\,L$$

m = barrel mass
c_v = specific heat
T = barrel temperature at Time = t
T_a = ambient temperature
H = heat transfer per unit area per round
R = rate of fire
A_i = inner surface area of the barrel
A_o = outer surface area of the barrel
D = outer diameter of barrel
d = inner diameter of barrel
ρ = density of barrel steel
L = length of barrel
h = heat transfer coefficient for the outer surface of the barrel

Radiation

Radiation loss becomes the dominant factor when the barrel reaches about 200°C. This is due to such loss being proportional to the fourth power of the absolute temperature. The following further quantity must therefore be taken from the above equation:

$$\epsilon\,\sigma\,A_0\,(T^4 - T_a^4)$$

Where ϵ = emissivity
σ = Stefan-Boltzmann constant
and T is measured in absolute values

Overheating Problems

Apart from the chance of a "cook off" already covered, the barrel may reach a temperature, normally taken to be in the region of 500°C, and if firing is continued, then damage may occur. Wear will increase considerably and rifling may be stripped and the barrel droop. These naturally lead to decreasing accuracy. Parts of the weapon itself may become too hot to hold, and this can make carriage difficult unless a carrying handle is provided.

Mitigating Heating Problems

There are a number of ways to help with weapon heating

- Provide changeable barrels, a topic already covered.

- Barrel cooling can be achieved by natural means or by using artificial cooling. Natural cooling is the widespread method used because of its simplicity. However, the cooling effect is small as shown below. Whilst heavy barrels heat up slowly they also cool slowly.

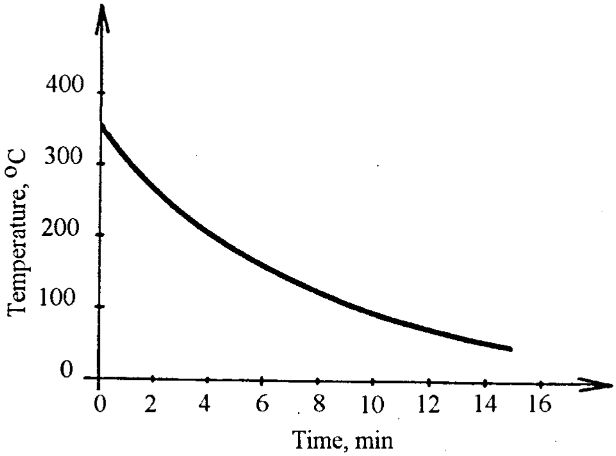


Fig 5.9 Cooling Rate for a 5.56mm MG Barrel

- Provide some form of forced cooling, either by creating an airflow across the barrel or liquid cooling. One would expect that providing fins on the barrel would help in cooling by increasing the surface area. Unless there is a good airflow across the fins, the heat loss is minimal. The Lewis gun used as a section LMG was a case in point. A longitudinally finned aluminium jacket was fitted over the barrel and air was drawn forward over it by the action of the muzzle blast. Most of the improvement was due to the greater mass of barrel thus provided rather than any cooling effect. Fins are often used to increase the strength of the barrel with minimum weight increase. A more efficient way of providing forced cooling is by using a liquid. Water has been and will continue to be the preferred liquid. It is usually available and does not have to be drinkable and vaporises at a low temperature that allows even better heat absorption. Although there has not been a water cooled MG since the Vickers, the idea is being seriously considered for the Chain Gun in AFVs . Whether such a system should be part of the general cooling system or stand alone has not yet been decided. However any such cooling would greatly benefit the crew. Barrel changes during engagements would become a thing of the past. The extra weight, vulnerability to enemy action and icing in very cold climates, while making the system unwieldy for the infantry, would not inconvenience those in AFVs.

- By using a hard metal, such as chromium, to line the barrel, the onset of wear and erosion can be offset. Another method tried was to replace the initial portion of a barrel with a stellite liner. Stellite is a very hard cobalt alloy that does not wear or erode easily at high temperatures. However it is not easy to work and fit. Indeed the gap between the stellite and the barrel steel has caused the stripping of the gilding metal from ball rounds and the premature ignition of incendiary type rounds in the bore. Until the whole length of the barrel can be fitted with stellite, such an idea cannot be safely used. Aircraft cannon would benefit most from being fitted with a stellite barrel.

- A common way of reducing barrel temperature is to increase the mass of the barrel. This increases the thermal mass so that, although the heat input to the barrel will be the same, the temperature rise for each shot fired will be reduced. The effect of increasing the barrel mass on temperature for a constant rate of firing for a 5.56mm calibre machine gun is shown in Fig 5.10.

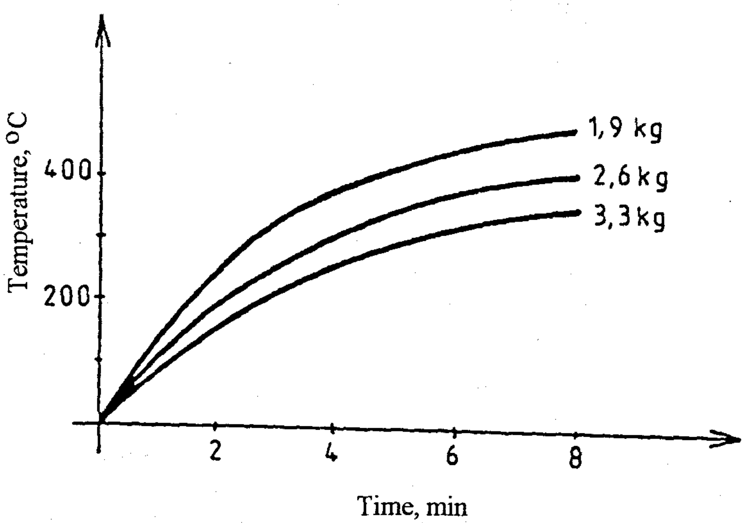


Fig 5.10 Effect of Increasing Barrel Mass on Temperature
(5.56mm MG with the same firing rate)

6.
Blow Back Operation

Basic Principles

Definition

The "blow back operation" of a small arm is defined as "a method of operation in which the energy required to carry out the cycle of operations is supplied to the bolt by the backward movement of the cartridge case, caused by gas pressure".

Types of Blow back

The blow back principle can be sub-divided into four categories:

- Pure blow back.
- Advanced primer ignition.
- Blow back with delay.
- Blow back with a locked breech.

Forces

Having seen how the pressure has developed in the previous chapter, its effects can be studied. The pressure produced inside the case acts in every direction. The pressure exerted on the base of the bullet produces a force of magnitude pressure multiplied by the cross-section area of the base of the bullet, which drives the bullet up the bore. The case is forced outwards and this seals off the chamber to provide obturation and so prevents the backward escape of the gas through the breech closing mechanism. When considering this expansion of the case it should be noted that, with the high pressures developed in modern rounds, a dry cartridge case will grip the chamber walls with great force and this force will resist any backward movement of the case whilst it is maintained by the pressure.

In addition to expanding the case radially, there will be a forward force on the case if the neck is tapered or bottlenecked and a large backward force equal in magnitude to the pressure times cross-section area of the interior of the base of the case. This latter force will drive the case rearwards against the face of the bolt. When the case movement rearwards is resisted by a locked bolt, the forward movement of the front part of the case expands the tapered or bottlenecked portion to fill up the gap between the case and the small cone of

the chamber. Thus the walls of the cartridge case are placed in longitudinal tension. But if the bolt allows the case to move rearwards it will be driven back by a force equal to the difference between the backward and forward components of the actual force developed within the case. The net effect of this difference is to produce a force, driving the bolt back, equal to the pressure multiplied by the cross-section area of the bore.

Unlubricated Case

Firstly let us consider a completely unlubricated case. The case is expanded radially and this produces a very high pressure metal to metal contact between the case and the chamber. At the same time if there is any spare space behind the base of the case it will be filled by the case being driven backwards by the pressure acting on the interior cross-section area of the base. If this space is excessive the cartridge case will stretch plastically until the base is in firm contact with the breech block face and the taper of the case is hard up against the small cone in the chamber. If the space is too large or the resistance of the breech block is inadequate to prevent the stretching of the case from exceeding the allowable elongation, the case will separate. The weakest portion of the NATO 7.62mm case will withstand a longitudinal tensile force not exceeding 4.35MN. The force produced if the chamber wall grips the neck of the case and the base is unsupported is about 72MN. The case therefore ruptures or separates.

The tendency of the case to move backwards to take up excessive cartridge headspace also has an effect on the design of the cartridge case employed in blow back operated guns. If a bottleneck or heavily tapered case is used the forward component of the pressure will force the shoulders forward and so deform them to fill the space left when the case is moved back. This can result in a ruptured case if the deforming force produces a stress exceeding the ultimate tensile strength of the metal. It will be found that parallel sided and slightly tapered cases are used for this type of operation. This shape is very suitable because as the case moves back through the operation, the obturation of the gases is maintained. When it is required to have one round that must be used in a number of weapons with different operating systems, such as the NATO 7.62mm or 5.56mm rounds, then the parallel sided case cannot be used.

Lubricated Case

Now consider the situation when the case is lubricated using a coating of oil or grease. This provides a continuous film, which will prevent metal to metal contact between the cartridge case and the wall of the chamber. The case can now slide easily in the chamber because there is virtually no frictional resistance and any excess cartridge head space can easily be taken up without fear of rupturing the case. The lubricated case has been very popular and has been used amongst others by the Schwarloze machine gun and the Breda light

machine gun in rifle calibre and the 20mm Oerlikon and Polsten. The practical difficulties in using lubricated cases for service weapons are many. The presence of sand, dust, dirt etc in the lubricant acts as a grinding paste and causes considerable wear of the gun mechanism and the chamber and can even cause a stoppage. Some ammunition manufacturers still provide their cartridge cases with a special finish, not only to inhibit corrosion, but also to help extraction.

Fluted Chamber

Modern designers have rejected lubricated cases in favour of employing a fluted chamber. In this method of reducing metal to metal contact of case and chamber, a series of longitudinal tapered channels are cut into the neck of the chamber, and over the small cone running out half way along the long cone. The expansion of the neck of the case as soon as the primer produces pressure, allows the gas to enter these grooves to balance the internal pressure. Thus the fore part of the case floats in a film of gas rather than lubricant and this succeeds in the desired effect of reducing the area of metal to metal contact. The typical design of a fluted chamber is shown below. This sort of fluted chamber is used in many weapons including the French FAMAS rifle and AA52 general purpose machine gun, the Swiss general purpose machine gun, the SIG 710.3 and the German Heckler & Koch blow back designs G3, MP5, and HK53 amongst others.

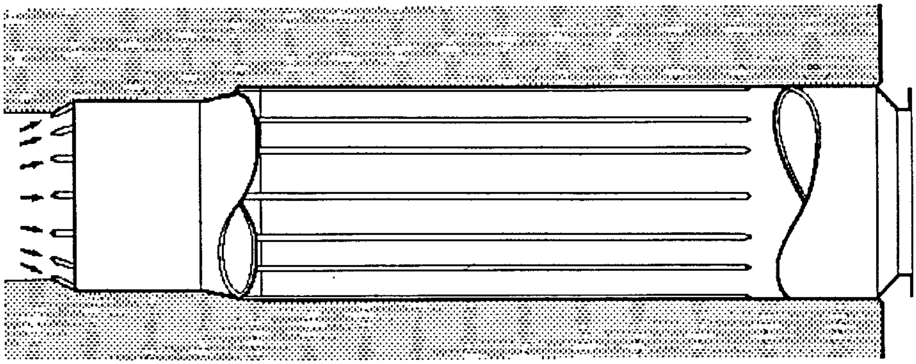


Fig 6.1 Fluted Chamber

Rearward Movement

When the pressure drops sufficiently to allow the case to contract enough to free itself from its grip on the chamber wall, the remaining pressure will drive the cartridge case bodily to the rear, pushing back the unlocked breech block and imparting sufficient energy to it to enable it to carry out the functions of ejection, storing energy in the return spring, feeding, chambering and firing the next round.

In a rifle calibre weapon the pressure will remain above atmospheric for some 3 to 4ms after the bullet has left the muzzle and for a longer period, some 7 to 8ms, in a longer barrelled 20mm weapon. This pressure alone is sufficient to operate most blow back systems.

Limitations

If the case moves back whilst the bullet is in the bore and the pressure is still above 77 MN/m^2 the case and bolt will accelerate very rapidly backwards. This can easily result in the rear end of the case emerging from the chamber totally unsupported. In spite of the increased thickness and hardness of the brass case at the rear end, the ultimate tensile strength of the brass is only about 345 MN/m^2 and so it can withstand unsupported only a very limited pressure. It is generally taken that in the rifle calibre round the case must not protrude more than 3mm (rising to 6mm in 20mm guns) when the residual chamber pressure is in excess of 5.2 MN/m^2. This places very strict limits on the design of the weapon.

Basic Problems in Blow back Designs

From the remarks above, it can be seen that there are two basic requirements for a blow back operated weapon:

The case must be free to move in the chamber:
- To take up excess cartridge head space.
- To provide the force against the breech block on which the entire system depends.

The case must be restrained in the chamber when the pressure is high or:
- There will be separated cases across the weakest section of the neck of the case whilst the case is still fully in the chamber.
- Or there will be an unsupported portion of the rear of the case emerging from the chamber and this will blow out.

These two requirements are mutually contradictory. The necessity to comply with them both has resulted in the comparatively sophisticated systems such as blow back with delaying devices and even blow back with a fully locked breech. These will be dealt with in the following paragraphs.

Simple Blow back

In this system blow back provides all the operating energy and the movement of the cartridge case is restrained and controlled solely by the mass, and inertia of the breech block and the strength of the return spring. A typical simple blow back system is illustrated in Fig. 6.2.

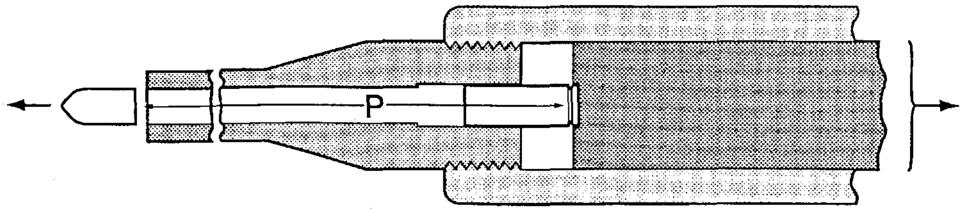


Fig 6.2 A Typical Simple Blow Back System

The mechanism consists of a chamber, housing a parallel sided cartridge case, and a stationary breech block, which supports the rear end of the case in the chamber. The bolt is unrestrained in any way and is quite free to move back. Behind the bolt is a fairly heavy spring which stores the kinetic energy imparted to the bolt and returns the bolt to its forward position after each round is fired. Within the bolt is a firing pin, or striker, which contains its own spring to drive the pin forward when released or the firing pin can be driven forward by a hammer.

When the cartridge is fired the pressure of the gas generated drives the bullet up the bore and at the same time an exactly equal force drives the cartridge case rearward against the resistance of the bolt. The pressure generated is not high and the parallel sided case provides complete obturation as it slides back. The elastic limit of the brass is not exceeded and so the case rapidly returns to its original dimensions when the pressure has passed its peak and the case does not bind to the chamber.

The weight of the breech block is so calculated that it does not permit a movement of more than 3mm during the period of time – about 5 ms – that the pressure is above 5.2 MN/m^2. This gives a mean velocity in the 5 ms of slightly over 0.66 m/s. The bolt is subjected to an accelerating force for about 6 ms in a rifle length barrel and of course rather less in a pistol. After this the gas pressure is zero and the force available to accelerate the bolt is zero but the case and bolt have now acquired sufficient momentum to continue to move back. As the cartridge case pushes the bolt back it extracts itself from the chamber and is ejected. The bolt slows due to the resistance of the return spring and the buffer, if one is fitted.

When the bolt velocity reaches zero all the kinetic energy imparted to it (less extraction, ejection, friction and possibly cocking losses) has been converted to the potential energy stored in the spring. The return spring drives the bolt forward to pick up a fresh round from the magazine, feed it to the chamber, chamber it and come to rest behind it.

Just before the bolt reaches its fully forward position the potential energy of the spring, less losses due to the feeding and chambering processes and

friction, has been fully converted into the kinetic energy of the bolt and cartridge. Thus the bolt is moving at a high velocity and the kinetic energy it possesses must be absorbed, partly by crushing up the cartridge case and the remainder by impact. When the trigger is pulled again the cycle will be repeated.

When used on fully automatic weapons, a lack of accuracy is caused by the vibrations set up by the heavy breech block and the changes of the centre of gravity during firing. If the mass and strength of the return spring and hammer and friction losses were ignored, the mass of the breech block of a low powered .22 rim fire cartridge would be about 2kg. In practice this is reduced and so a weight of probably about 1kg is acceptable. A similar calculation for a military rifle firing the NATO 7.62mm round shows that a bolt mass of 18.2kg would be required, whilst for a 20mm heavy machine gun it has risen to 227kg. From this it is obvious that the simple blow back system is suitable only for low powered rounds of small calibre and its use is restricted to military pistols and small SMGs firing low powered cartridges and to a large number of sporting pistols and rifles of about .22 calibre. The table below gives details of some military weapons operated on the simple blow back system. There are many more modern weapons, such as Micro UZI (9x19mm), and P90 (5.7x28mm), that use pure blow back.

Characteristics of Simple Blow Back Weapons.

- Unlocked breech.
- Heavy "inertia type" breech block.
- Simplicity.
- Strong return spring.
- Usually a parallel sided cartridge case (P90 is one exception).
- Limited accuracy in hand-held automatic fire due to movement of heavy block and consequent vibrations, during firing.

Table 6.1 A Selection of Simple Blow back Operated Weapons

Weapon	Makarov	Stechkin	VZ 61
Origin	USSR	USSR	CZECH
Popular name	PM	APS	Skorpion
Calibre (mm)	9	9	7.65
Case Length (mm)	18	18	17
Length (mm)	160	226	269.25 (1)
Weight empty (kg)	0.663	1.022 (2)	1.544 (3)
Barrel Length (mm)	92.2	127	111.75
Magazine Capacity	8	20	10 or 20
Types of Fire	SA	Selective	Selective

Weapon	Makarov	Stechkin	VZ 61
M V (m/s)	315	340	305
Practical Range (m)	50	50 (4)	50 (4)
ROF Semi-auto	35	40	35
ROF Auto	N/A	750	835

Notes: (1). 513mm with wire stock extended.
(2). Pistol only. Add 0.5 kg for holster-stock.
(3). With empty 20 round magazine.
(4). With stock in use 200 m.

Blow back with Advanced Primer Ignition (API)

In the simple blow back system described, the bolt is heavy and although it travels forward fairly slowly it has quite a lot of kinetic energy which is lost by crushing the cartridge case at impact. The bolt is stationary when the next round is fired and the entire rearward impulse is available to give the bolt a rearward momentum. This leads to a heavy bolt to keep the velocity down to a level where no undue amount of cartridge case is allowed to project unsupported whilst the pressure is high. The kinetic energy possessed by the bolt as it chambers the round can be used to good purpose if it is possible to time the ignition so that a round is fired just before the bolt reaches the limit of its forward travel. The impulse of the propellant explosion now has two functions:

- To slow and stop the forward moving bolt.
- To propel the bolt to the rear.

In practice the final forward velocity of the bolt induced by the return spring is very nearly the same as the initial backward velocity produced by the propellant impulse. Thus if the bolt velocity is unchanged, the mass of the bolt can be reduced to half its previous value because only half of the firing impulse is being used to drive the bolt backwards.

Other advantages follow from the use of advanced primer ignition. The cartridge case is placed in compression due to the friction forces resulting from the high gas pressure as the bolt is slowed down in its forward movement. Compressive stresses do not cause case separation and therefore lead to no ill effect. When the case is driven back the time during which it is subjected to longitudinal tensile stress is halved. Since the distance the case can project without support remains constant, the bolt velocity can be twice as high as in the simple blow back system. This increase in permissible velocity will allow a further reduction in bolt weight and also an increase in the rate of fire. The net effect of advanced primer ignition by itself is to reduce the bolt weight by a factor slightly greater than 2. This means that the weight of a rifle bolt operated

on this system could be reduced to 9kg and that of a 20mm gun could come down to somewhat less than 114kg. These figures are still completely impractical. No rifle working on advanced primer ignition has been adopted into the service of any country but there have been many heavy machine guns and a very considerable number of sub machine guns working on this principle.

Sub Machine Guns

Let us look at a typical example of an advanced primer ignition sub machine gun. The figure below shows the British L2A3 sub machine gun.

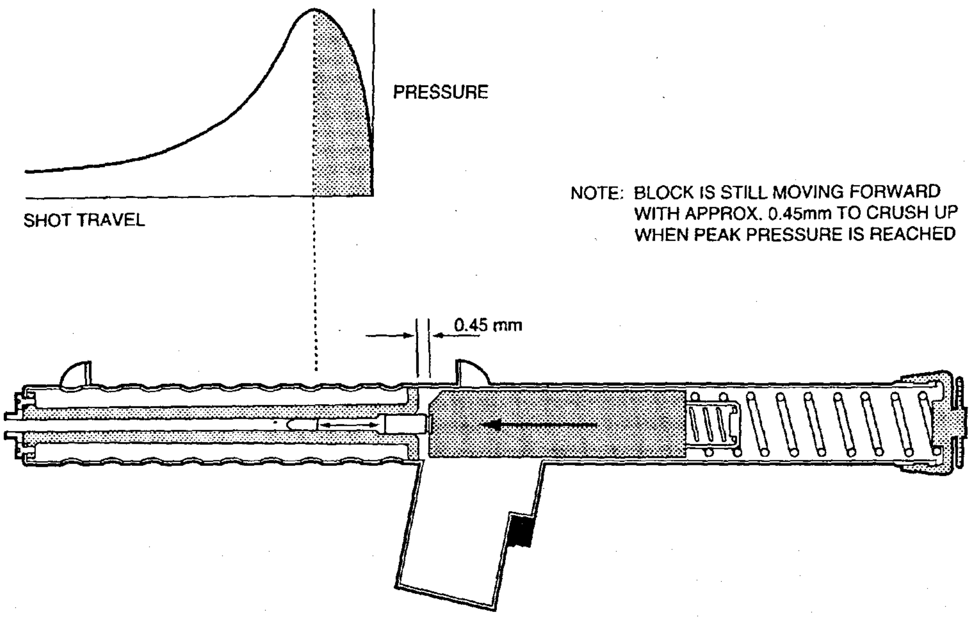


Fig 6.3 Advanced Primer Ignition - 9mm L2A3, SMG

When the weapon is cocked ready for firing the breech block is to the rear, held by the sear. The return spring is compressed thus storing energy. When the trigger is operated the sear is depressed and disengaged from the bent of the breech block which is driven forward by the spring. The face of the breech block picks up a cartridge from the magazine, drives it forward and the nose enters the chamber. The round at this stage is angled across the breech block. As the cartridge feeds into the chamber, the continued forward movement of the block forces the round to align itself with the axis of the bore, and the cap is lined up with the fixed striker on the front face of the breech block. As soon as the friction force between round and chamber is sufficient, the cap is fired. The cap is thus fired while both the cartridge and the breech block are moving forward. The precise moment when the cap is detonated depends on a number

of factors including:

- Dimensions of the chamber and round.
  A chamber with the smallest permissible diameter and a cartridge case with the largest diameter will produce early firing, whereas a chamber on the largest permitted diameter and cartridge case on the smallest diameter could fire late.

- Friction in the chamber.
  The better the finish of the chamber the later the firing will be given for a given dimension of cartridge case and chamber.

As a broad approximation the bolt has some 0.76mm to go before it encounters the breech face. The impulse given by the burning of the propellant causes a rapid slowing up of the forward movement of the breech block. When the maximum chamber pressure has developed as shown in Fig 6.3, the breech block is still 0.46mm clear of the rear face of the chamber and still moving forward. Thus while the bullet is still in the bore the breech block is either moving forward, momentarily at rest, or being driven slowly backwards. Since the cartridge case is parallel sided the breech will be fully obturated until the cartridge case mouth leaves the chamber. The further rearward movement of the block stores energy in the return spring and the breech block is then either held up on the sear or continues forward to complete the cycle of operations. This reciprocating movement of the breech block causes considerable changes in the centre of gravity of the weapon and also sets up vibrations when the case is being crushed up. The small sub machine gun as a class is unlikely to provide accurate fire.

Heavy Machine Guns

The Polsten, a 20mm gun with advanced primer ignition, depended upon the development of a specially shaped chamber and a lubricated case. With this shape the diameter of the base of the case was reduced to a size less than that of the maximum case diameter and so the bolt head carrying the extractor could follow the case right up into the chamber which is longer than the length of the round. The effect of this is that the case is fully inside the chamber and fully supported whilst moving forward and also when the case is blown back it is fully supported for more than the length of a round and there is no fear of a burst case. This means that instead of travelling 6mm in 5ms the case can now travel some 50mm in 5 ms giving a mean bolt velocity 8 times as high as in the simple blow back case and producing a much higher rate of fire. Alternatively the breech block can be reduced to about 18kg. No one would design a MG like the Polsten today. It suffered from many stoppages, due to the numerous safety features designed into it.

Dangers in API Systems

The entire advanced primer ignition system depends on the primer being detonated at the right moment whilst the breech block is moving forward. If detonation is either significantly early or late the system will not work. The hazards to which the system is subject are:

Early Firing. The build up of carbon in the chamber can cause early firing. Another cause is the entry of grit or dirt especially on lubricated ammunition. Early firing means that the peak pressure develops before the case is fully inside the chamber. This leads to a burst case.

Late Firing due to a Hang Fire. The bolt may well have bounced from the crushed up case and be moving backwards when the firing takes place. In this event the bolt will be driven back at a velocity of nearly 3 times its normal rate. This means its kinetic energy is nearly 9 times its normal and the return spring may well fail to assimilate such a high level of energy. This can produce serious damage to the back plate buffer and springs.

Mechanical Obstruction in the Chamber. A separated case will leave the forward portion in the chamber. The next round will be unable to enter the chamber fully and could be fired prematurely. With 20mm ammunition which is frequently fuzed the resulting case blow out could set off the high explosive filling.

Hand Chambering. If a round is hand chambered and the bolt is released on to it, the case will be stationary, fully home, and the bolt velocity will be terminated by impact long before the peak pressure is reached. This will result in a rearward bolt velocity of between 2 and 3 times the normal and the risk of a burst case could well lead to a damaged gun.

Safety Devices

Although none of the dangers apparent in the system are of great importance in a 9mm powered sub machine gun, they can be extremely hazardous in weapons of 20mm calibre. The devices likely to be incorporated before such a weapon will be accepted for service are:

Positive Firing. The position at which the primer is struck is controlled by the position of the breech block relative to the chamber. The usual arrangement is where the hammer in the bolt is driven against the firing pin when the bolt is in one unique position relative to the body of the gun.

A Hooded Chamber. A hooded chamber can minimise the effects on the gun and the crew of early or late firing. The hood or overhang of the barrel screens the effects of the unsupported case bursting.

A Double Loading Stop. When a separated case occurs, the case fragment left in the chamber depresses a stud which operates a holding open device thus ensuring that the breech is retained to the rear until the chamber obstruction is removed.

A Holding Open Device. The weight of the breech block is considerable and the springs are powerful. If the block were allowed to go forward when the ammunition supply is exhausted, damage would be caused if there were no firing impulse to cushion the impact. The crew would also have to expend both time and effort in manually recocking the gun.

Weight Distribution in Larger Calibre Guns

The system requires a heavy breech block and strong springs. If all the weight were concentrated in the block itself, the block would be very large in diameter and the gun body containing it would be unacceptably heavy. To overcome this the designer wraps the heavy return spring round the barrel which becomes the spring guide and uses side members to connect the springs to the breech block as with the Oerlikon heavy machine gun and the wartime Polsten.

Thus the breech block is small enough and light enough for a gun crew to handle and the gun body is kept down to small dimensions. The total weight of the block is thus made up of:

- The breech block.
- Two side members.
- One third of the weight of the return spring.

Ammunition of Varied Impulse in API Systems

The advanced primer ignition system depends for its functioning on the destruction of forward bolt momentum and imparting a recoil velocity to the block by the residual impulse from the propellant charge. The first round must be fired with the breech block held back by the sear so that the block will not have its full forward travel. The block is being driven forward by the partly extended spring with no rebound velocity from the buffer. It will chamber the first round with sub-normal velocity and so the firing impulse will throw the bolt back with a greater than normal velocity. The buffer and return spring will throw the bolt forward again carrying the second round faster than normal velocity and this increased forward momentum will result in a lower recoil velocity after the second round is fired. Thus the recoil velocity is high after the first and all odd numbered rounds and low after the second and even numbered rounds. In a burst fired with ammunition of a constant level of impulse this effect is not pronounced and indeed in a burst of several rounds the velocity of the bolt will level itself out.

Where "mixed" ammunition with differing impulse is used the effect can be amplified to the extent that the bolt velocity can be built up to a dangerously unstable level. Suppose a drum of 20mm ammunition were to be loaded alternately with armour piercing ammunition of large impulse and high explosive ammunition of a lower level of impulse. The first round will produce violent recoil of the bolt, which stresses the buffer and return springs to a higher degree than usual. The second round will be fed with extreme velocity but the impulse being low the bolt will barely return to the sear. The slow forward velocity of the third round loads an armour piercing round which hurls the bolt back violently. Thus a motion is set up which can destroy the gun and recoil system. The Oerlikon has been shown to be particularly susceptible to this effect.

Characteristics of Blow Back with Advanced Primer Ignition

- Breech block still moving forward when the primer is fired.
- Unlocked breech.
- Heavy breech block.
- Powerful return springs.
- Simple design.
- Special safety devices to prevent damage from double feed, early ignition, or hang fire.
- Parallel sided cartridge cases.
- Lubricated cases.
- Poor accuracy in hand held weapons due to the movement of heavy breech block during firing.
- Susceptibility to variation in ammunition.

Blow Back with Delay or Retarded Blow Back

Although the advanced primer ignition represents more than a 50% saving of weight in the reciprocating parts compared to a pure blow back operated weapon, it can only be used in small calibre sub machine guns and in large heavy machine guns carried on a massive mounting. It is not suitable for a weapon requiring an accurate first round shot because, not only are the reciprocating parts heavy, but the system depends on firing from an open

breech position which leads to inaccuracy from two sources:

- The change in the centre of gravity as the heavy bolt reciprocates.
- The long lock time, which will be found in any open breech system.

Both of these disadvantages are overcome in what is known as "delayed blow back". In the delayed blow back system the rearward movement of the bolt, after the round is fired, is retarded until the pressure has dropped to a level where it can safely be allowed to drive the bolt face back. This permits the cartridge case to become unsupported, without fear of danger.

This system almost invariably depends upon some mechanical arrangement using light components which ensures that the bolt must act through a very considerable mechanical disadvantage to overcome inertia before the bolt can readily move rearwards.

Whatever the detailed arrangements used to produce the delay, the essential part of the design must be to ensure that the delay is not uniform in its action. It must impose maximum restraint on the movement of the bolt face immediately firing takes place and pressure is high. Yet as soon as the pressure drops off it must allow progressively increasing freedom to the bolt to accelerate rearwards to reach a relatively high velocity without which a reasonable rate of fire is impossible. This aspect is illustrated in Fig. 6.4.

Mechanical Delay

If we examine Fig. 6.4, we note that when the weapon is ready to fire, the arm attached to the block is very nearly coincident with the arm attached to the body. Both can be regarded as being at an angle θ to the axis of the bore. The gas force P applied to the breech block can be broken down into two components proportional to $P \cos \theta$ which acts along the arm attached to the block and proportional to $P \sin \theta$ which acts at right angles to the arm attached to the body. It is this force proportional to $P \sin \theta$ which causes the arm attached to the body to rotate which it must do as the block moves back. When θ is very small as it is when the gun is fired, the force $P \sin \theta$ is very small and so the angular acceleration of the arm is small and the bolt face moves backward very slowly. As θ approaches $90°$, the force applied to rotate the arm increases and the rearward velocity of the bolt increases.

This design, in practice, was extremely sensitive to the effect of barrel length. A shortening of the barrel caused an earlier loss of gas force and so there was not enough energy imparted to the breech block to carry it fully to the rear. Conversely an extra inch of barrel length produced a violent backward motion of the breech block which produced damage to the return spring and the rear of the body casing.

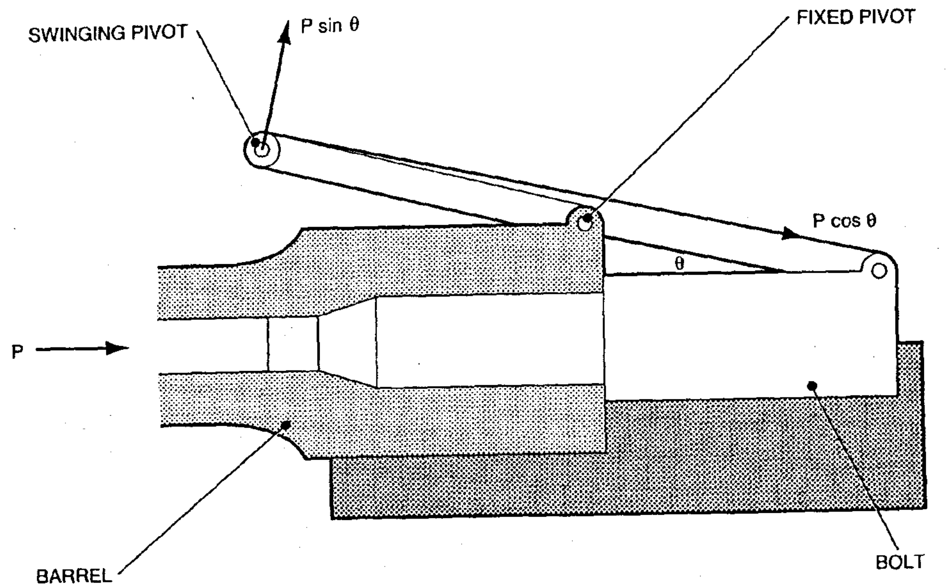
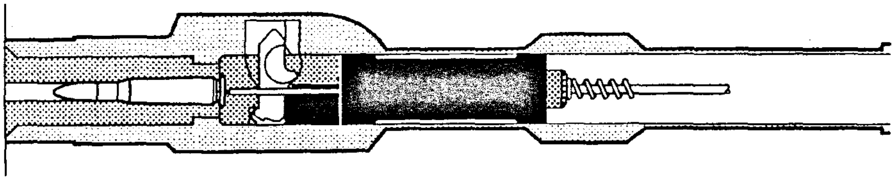


Fig 6.4 Differential Breech Delay - Schwarzloze MG

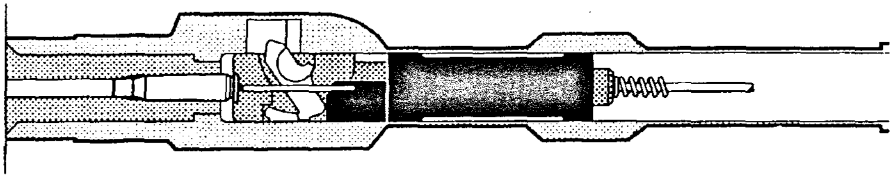
Modern European practice is not to employ toggle-joints with their large moments of inertia but to use two-part breech blocks. Relative motion between the two parts is obtained by means of a simple internal lever or a pair of rollers. Fig. 6.5 shows the system used in the French general purpose machine gun the AA52.

When the weapon fires the lever carried in the bolt head is forced hard back into the recess in the body of the gun. The lever is thus compelled to rotate. The fulcrum of the lever is not at the centre point so that there is a velocity ratio obtained as the lever rotates and this causes the bolt body to be accelerated relative to the bolt head. When the pressure has dropped to an acceptably low level, the lever rotates out of the body and the residual blow back action forces back the entire breech block with no further change in the displacement of the two parts. Energy is stored in the return spring that drives the breech block forward again. The lever cannot rotate until it comes opposite the recess in the body and so the bolt body is held back. When the round is fully chambered the lever rotates and the bolt body comes forward, strikes the firing pin which is held in the bolt head and completely closes up the gap between the two sections of the breech block.

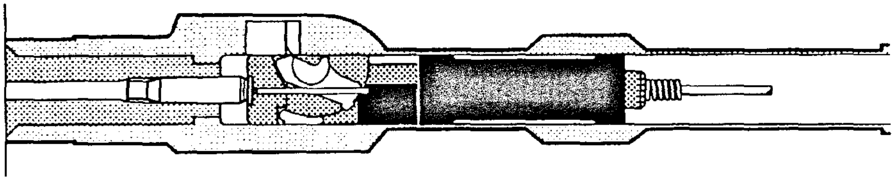
The essential element of the design is that while the pressure is high a slight rearward movement of the breech face produces a movement of three times the displacement, and therefore the velocity, of the bolt body which thus acquires momentum. When the lever is out of the body the bolt head is accelerated back at a velocity that is increased by the residual gas pressure.



1. POSITION AT FIRING



2. LEVER ROTATING.
BOLT BODY MOVING BACK.



3. LEVER DISENGAGED FROM BODY.
ENTIRE BOLT ASSMBLY MOVING BACK.

Fig 6.5 The French AA-52 GPMG

The diagrams in Fig. 6.6 show the West German G3 automatic rifle. This rifle was designed in Spain (CETME) and was derived from the wartime German St G 45. It is often called the CETME. The top diagram shows the weapon ready to fire with the case in the chamber and fully supported by the bolt head of the two-piece breech block. When firing takes place the gas pressure forces the cartridge case back against the breech face which is compelled to move rearwards. The bolt head carries two rollers that are engaged in recesses in the barrel extension.

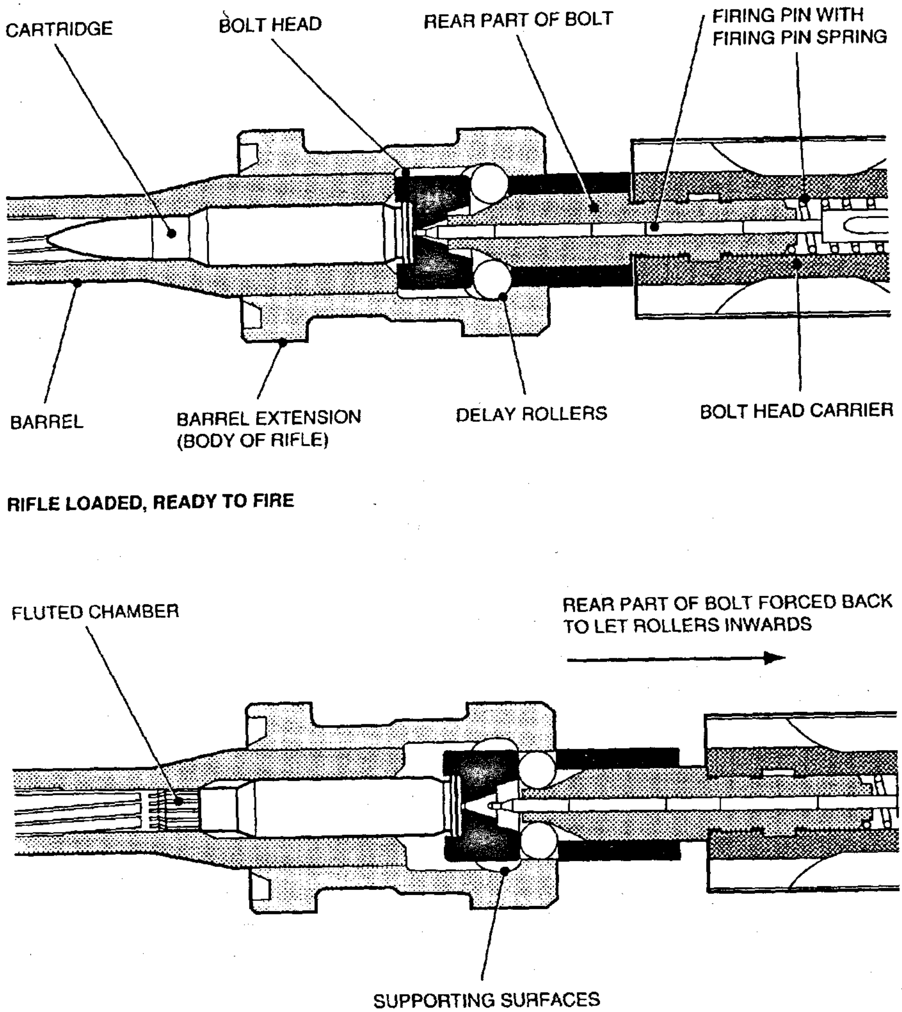


Fig 6.6 The German Rifle, G3 - Method of Operation

Before the breech block can move back these two rollers must be forced in to clear the recesses in the barrel extension. This is done by the reaction of the recesses to the firing force. The inward movement of the rollers is resisted by the inertia of the bolt body as it is driven backwards, by the action of the rollers over the inclined plane at the front of the bolt body. This slows down the rate at which the bolt head comes back. When the rollers are finally free from the barrel extension the bullet has left the muzzle and the two parts of the breech block are forced to the rear by the residual gas pressure.

The relative position of the two parts remains unchanged until the next round is chambered. The front part of the breech block is then halted and the rear

part is able to force the rollers out into the recesses in the barrel extension, in preparation for firing the next round.

The Swiss SIG 710–3 machine gun and SIG 510–4 rifle work on similar principles.

The differential action, whether it is obtained by means of a roller system or directly from a lever, in addition to initially limiting the bolt head of the breech block to a shorter movement than the bolt body, assists a relatively light spring to resist the rearward thrust of the case. Since for a small rearward movement of the case and bolt head the bolt body is required to move a greater distance until the lever is disengaged or the rollers are freed from their recesses, the working load of the spring is thereby increased during this differential action.

The striker is also operated by the differential action between the two portions of the breech block. This ensures that the round cannot be fired until the lever is rotated in front of the shoulder in the body or alternatively the rollers are fully engaged in the recesses of the barrel extension. The position of firing is thereby controlled.

Mechanical delay is achieved by:

- Differential action between two portions of the breech block.
- Engagement of a lever or rollers in the gun body or barrel extension.
- Increase in return spring effect caused by initial differential action of the breech block.

Blow Back with a Locked Breech

In this system the weight of the breech block is reduced to the minimum compatible with the required strength. The breech block is locked whilst the pressure is high and after the point of maximum pressure has passed, the breech block is unlocked and the residual gas pressure forces the breech block back as in the simple blow back system.

The force chosen for unlocking the breech block may be produced from gas pressure or recoil of the barrel. But the energy required to operate the cycle is given to the bolt entirely from blow back and so it is not logical to describe these weapons as operated by a "combination of principles" as has been done in the past.

An example of a locked breech blow back operated weapon is the Hispano Suiza 20mm type 820L (see Fig. 6.7). The breech block carries a side plate on each side and a hinged strut on the bottom. When the round is chambered the

strut is forced down into the body of the gun by the side plates which then ride over it to hold it down. The position of the firing pin is controlled by a cotter pin passing through the side plates so that only when the side plates are fully forward can the round be fired. Any tendency of the side plates to bounce is prevented by a spring loaded inertia block.

When the round is fired the locking piece becomes a strut placed in compression and the breech block is firmly locked. The shell passes up the bore and uncovers a tapping through which gas passes into a cylinder above the barrel and then along a channel which bifurcates to allow pistons on each side to drive back the locking plates on the bolt. As soon as the locking plates are moved from their positions holding down the locking piece, the residual gas force and the angle at which the locking piece lies against the locking shoulder in the body allow the locking piece to rise and the breech block is blown bodily backwards.

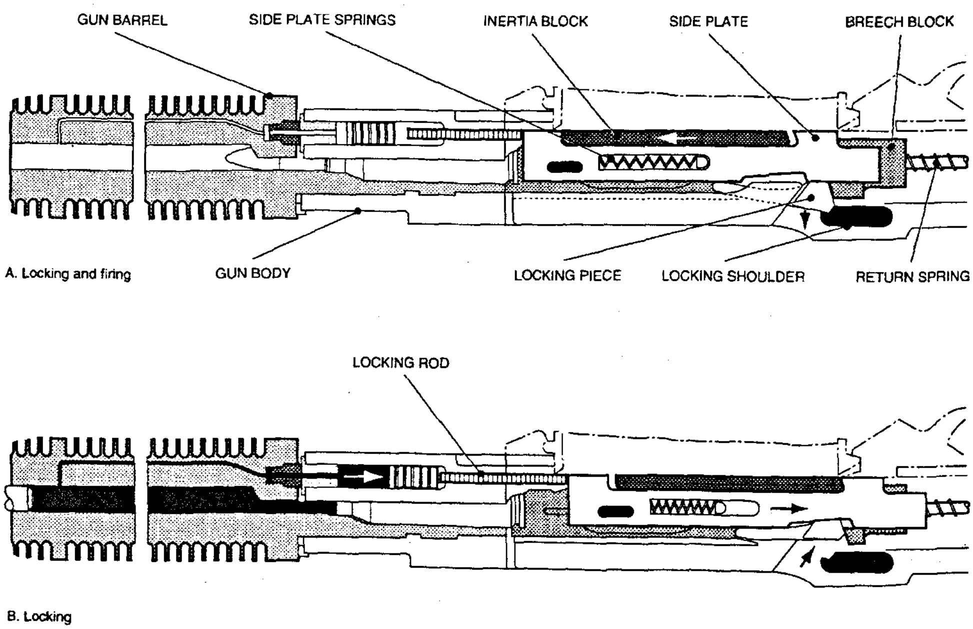


Fig 6.7 20mm HMG - HISPANO SUIZA, Type 820L

This system is very suitable for a heavy machine gun and is to be preferred to the delay device that loses simplicity and safety as calibre increases. An example of a hand held weapon firing from a locked breech and using recoil force to unlock the breech when the pressure has dropped to a safe level, is the Johnson .30in LMG shown in Fig. 6.8. This was developed in 1941 and used by the United States Marines in the Pacific campaigns.

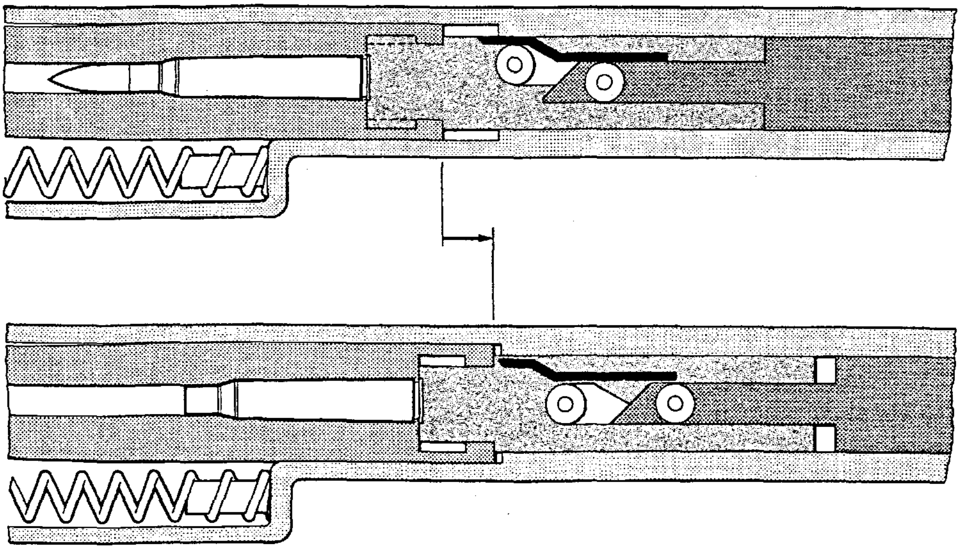


Fig 6.8 Johnson .30in LMG

The bolt that rotates to lock is in two parts. When firing takes place the breech block and barrel recoil together. The front part of the bolt or breech block carries a roller, which after 3mm free travel contacts a cam path in the body of the gun. This causes the bolt head to rotate and unlock. In so doing the rear part of the bleech block is forced back. As soon as unlocking is complete the residual pressure, which is now down to about 7 MN/m^2, forces the entire breech block rearwards to carry out the cycle of operations. The system is expensive, complicated and was not generally popular although it should be noted that the Johnson LMG weighed only 5.6kg as compared to the 8.6kg of the BREN gun.

Application of Blow Back Systems

The following are the main applications of blow back systems:

- For low powered rounds fired from sporting and target rifles and pistols, simple blow back is adequate.

- For sub-machine guns the advanced primer ignition system is almost universal.

- For rifles that must be fired from a closed breech, blow back with delay is used.

- For light machine guns and general purpose machine guns, blow back with delay is employed.

- For heavy machine guns there is the choice of advanced primer ignition or locked breech. The advanced primer ignition system is cheaper but produces less consistent fire and is more susceptible to the variation in the ammunition impulse. Some idea of the weight difference is shown in Table 6.2 which compares the Oerlikon 20mm gun operated by advanced primer ignition, with the Hispano Suiza 20mm Mk 2 which has a locked breech.

Table 6.2 Comparison of Oerlikon and Hispano Suiza 20mm Guns

	API 20mm Oerlikon	Locked 20mm Hispano Suiza
Breech Block Weight	3.1 kg	3.3 kg
Weight of other Recoiling Parts	14.89 kg	1.81 kg
Total Recoiling Mass	17.99 kg	5.11 kg
Weight of Gun	64 kg	48.2 kg
Rate of Fire	600 rpm	650 rpm

It should be noted that in all blow back operated weapons the breech opens early and as soon as movement has broken down the case obturation, fumes will be blown back through the breech. This is not important in an infantry weapon but where firing takes place in an enclosed space or inside a turret, arrangements must be made to ventilate the confined volume or the toxic fumes can prove to be dangerous.

The muzzle velocity given from a selected round will be less when a blow back weapon is employed because the rapid increase in chamber volume as the case moves back leads to some reduction in working pressure.

The blow back system has no provision for adjustment of power to allow for the increased friction in the working parts caused by fouling, dirt, sand, or other cause. The weapon will be set for excess gas. The action tends to be harsh when the system is clean and the accumulation of fouling gradually slows down the action with a consequent reduction of cyclic rate and a slowing up of the speed of case ejection.

If the weapon requires a barrel change system, blow back is particularly good as the barrel can be secured by a simple catch and readily withdrawn rearwards. The Swiss SIG 710-3 GPMG is particularly noteworthy in this respect and provides a fast barrel change.

Summary

A summary of the characteristics and normal uses of the four types of blow back operation is given in table 6.3.

Table 6.3 Summary of the Four Types of Blow back Operation

CATEGORY	SIMPLE BLOW BACK	ADVANCED PRIMER IGNITION	BLOW BACK WITH DELAY	BLOW BACK WITH LOCKED BREECH
Complexity	Simple	Simple	Less simple timing sensitive	Fairly complicated
Cost	Cheap	Cheap	Fairly cheap	Fairly expensive
Block	Heavy	Lighter	Generally two-part	Light
Case	Parallel sided, low power	Parallel sided, open breech	Any form, a fluted chamber is normally used	Any form
Type of Weapon	Very low power, usually pistol or SMG	SMG, few HMGs	All, usually rifles, LMGs	HMGs

All blow back weapons tend to suffer from the following defects:

- Toxic fumes.
- Fouling on bolt head and body.
- Reduced muzzle velocity.

7.
Recoil Operation

Definition

In this method of operation, the barrel is free to recoil in bearings in the body of the gun. The barrel is locked to the breech/bolt. When the propellant is ignited, the force that pushes the bullet up the bore also pushes the breech block rearwards. The breech block is firmly secured to the barrel, so the breech block pulls the barrel backwards. Later in the cycle the breech block is unlocked from the barrel and continues to the rear, when extraction and ejection take place. Meanwhile the barrel is returned to the forward position, followed by the breech block, a new round is chambered and the breech block again locks to the barrel.

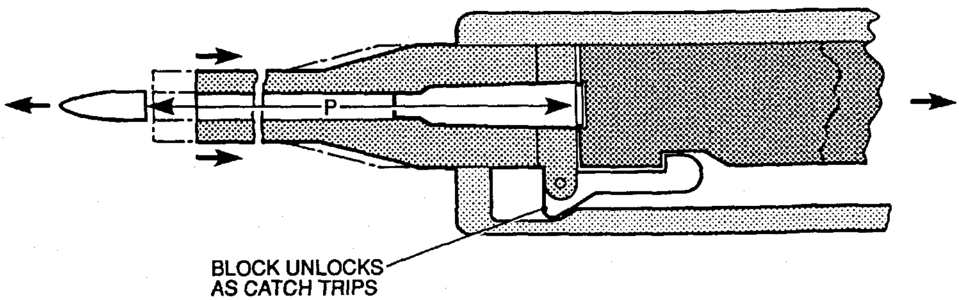


Fig 7.1 An Elementary Recoil Operated Gun

This movement of breech block and barrel is the source of energy for recoil operation. The point to be observed is that the recoil of breech block and barrel is relative to the gun body. All guns in which the breech block is locked to the body will recoil but since the entire weapon recoils there is no relative movement between barrel/block and the gun body, and therefore the gun cannot employ the recoil system of operation.

Recoil Operated Systems

There have been many examples of recoil operated guns in the past and there have been a very large number of detailed mechanical arrangements by which the system has been applied. These have varied widely but, in spite of these differences, all recoil operated weapons can be regarded as falling in one of two basic categories. These are known as long recoil and short recoil.

Long Recoil

Long recoil is a system in which the breech block and barrel are locked together and both move to the rear over a distance which exceeds the length of an unfired round. This movement is the source of energy to operate the system. When the rearward movement is completed the bolt is unlocked from the barrel and is held to the rear whilst the barrel runs out leaving the empty case on the breech block face. When the barrel has moved forward far enough to allow sufficient space for feeding, the bolt is released. At this stage the barrel will have only a short distance of further forward travel to complete its run out. The bolt is then driven forward by the return spring to carry out feeding and chambering, and it is then locked to the barrel prior to the next round being fired.

Components

The essential components of a long recoil operated gun are the bolt, the locking system, the return spring and sometimes a barrel return spring. These elements are shown in diagrammatic form in Fig. 7.2.

Cycle of Operation

The general principles of the operation of a long recoil system are as follows. The round is in the chamber with the bolt locked to the barrel. This situation is shown in the top diagram Fig 7.2.A. When the round is fired the breech block is driven back pulling the barrel with it. The influence of the uncompressed return spring is small and the recoil acceleration is decided by the magnitude of the recoiling mass. The pressure is sustained for a short time after the bullet has left the muzzle but it soon drops to zero and the bolt and barrel move to the rear under the momentum they have acquired. The increasing resistance offered by the barrel spring and return spring slows them down until they come to rest fully recoiled. This is shown in Fig 7.2.B. The bolt is still locked to the barrel and the only part of the cycle of operations completed–except firing–is the storage of energy in the springs. The bolt is held to the rear and the barrel is released (see Fig 7.2.C), moving forward to produce extraction and ejection. When the barrel has gone forward sufficiently the next round is fed forward. The barrel will have a lot of kinetic energy as it runs out and this must be absorbed by a buffer in larger calibres or by impact in smaller weapons. When the barrel completes its run out it operates a bolt release mechanism and the bolt is driven forward to feed and chamber the next round and then lock on to the barrel. The kinetic energy of the bolt is absorbed by operating the locking mechanism, seating the round and by impact on the rear of the barrel.

Design Features

Long recoil presents no problem of cartridge case movement in the chamber since the locked period takes up half the interval between shots. It does

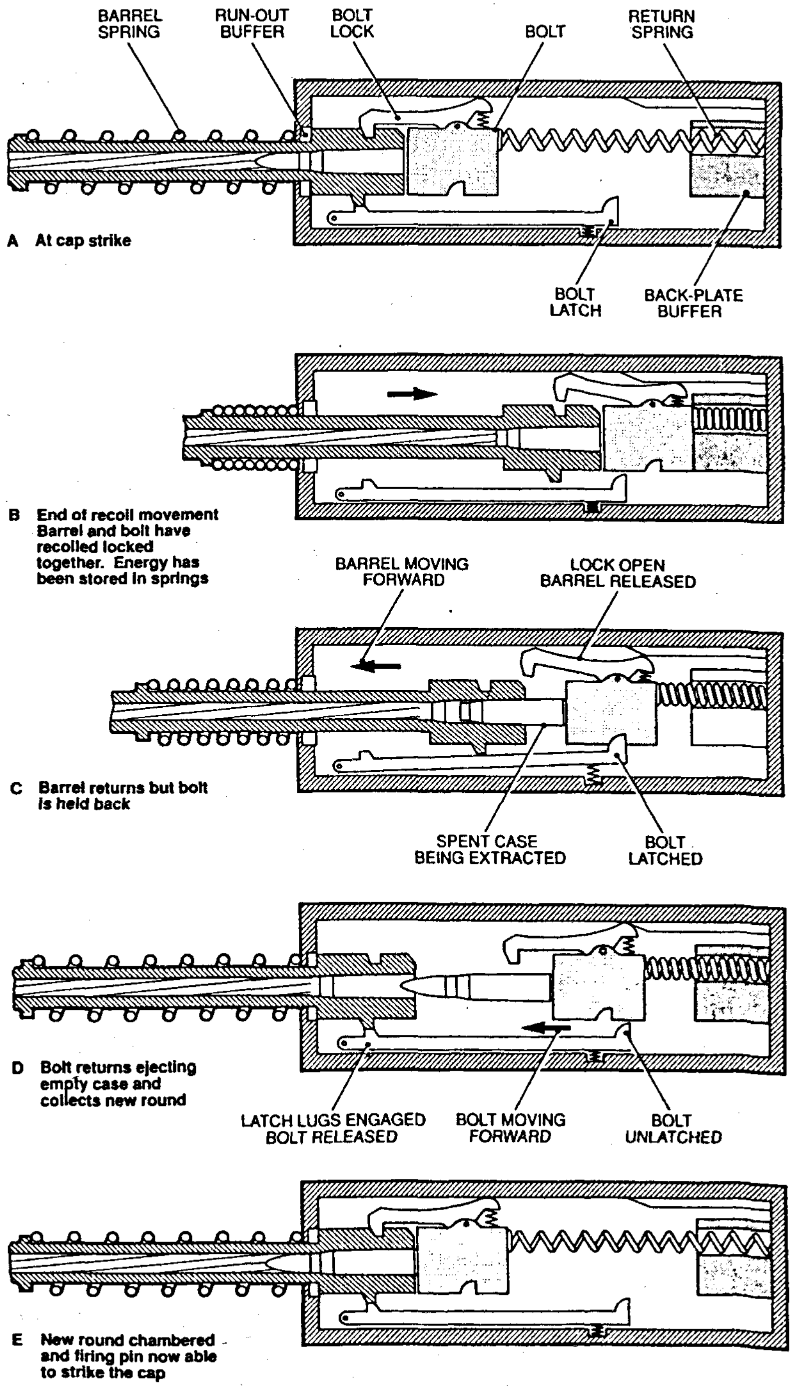


Fig 7.2 Elements of Long Recoil System - Diagrammatic

present problems of making efficient use of the recoil energy available. If a large calibre weapon such as a 30mm cannon is considered, the considerable cross-section area of the bore and the high pressure, produce extremely large recoil forces which can result in a violent action producing a large amount of recoil energy. This has to be dissipated in the buffer-recuperator. In a long recoil gun the rearward thrust of the recoil force is expended in producing motion of the combined masses of the breech block and the barrel over a long distance. Since these masses are quite considerable, the rearward velocity is comparatively low and the resulting kinetic energy is not excessive. Also since the recoil energy can be absorbed over a relatively long movement, the force required to absorb the energy can be kept within reasonable limits thus giving a low trunnion pull.

Since the breech block does not become unlocked until the full recoil has been accomplished, half the reciprocating cycle elapses before the normal functions of extraction, ejection and feed can commence. This inevitably means an extremely low rate of fire – probably about one fifth to one quarter of the rate achieved in the same calibre using a different method of operation. Thus the main practical results of using a long recoil operated system are:

- Reduced stress in the system – particularly in the recoil-recuperator mechanisms. The trunnion pull will be low.
- A very slow rate of fire.
- A complex and expensive mechanism and heavy expensive barrel bearings.
- A large change in the centre of gravity as the barrel reciprocates.

These facts have ruled out the system for many years as a military consideration for smaller calibres. In fact the self loading shot gun is the only example met in modern hand held weapons. Whether there is any future for this system in a military self loading rifle is very doubtful. There are advocates of its employment who claim that the slow rate of fire allows the soldier to fire on full automatic at 200 rounds a minute and correct the tendency for the muzzle to rise between shots.

RARDEN 30mm Cannon

There is one field of application where the low trunnion pull and the slow rate of fire make it advantageous. This is the cannon designed to be fitted in an Armoured Personnel Carrier (APC) or a Combat Vehicle of the reconnaissance type, and intended to be used against enemy lightly armoured vehicles or APCs. The British RARDEN 30mm cannon was evolved as a long recoil operated weapon and this system was selected precisely for these reasons. The method of operation is shown in Fig. 7.3.

- The top diagram shows the gun loaded and ready to fire. The barrel is fully run out, the round is chambered and the only action required is for the solenoid or firing button to be operated.
- In the second drawing the barrel has recoiled 330mm and is at the fully rearward position. The sliding breech block is fully open and the rammer claw grips the empty case.
- The last figure shows the barrel fully forward, the rammer claw has rotated and placed the empty case in the ejection chute. The rammer rotates back bringing a live round into line with the bore.
- The rammer next moves forward under the action of its spring, feeds the round into the chamber, releases the breech block catch and allows the breech to close. The closing breech pushes the rammer aside and the gun is then as shown in the top diagram.

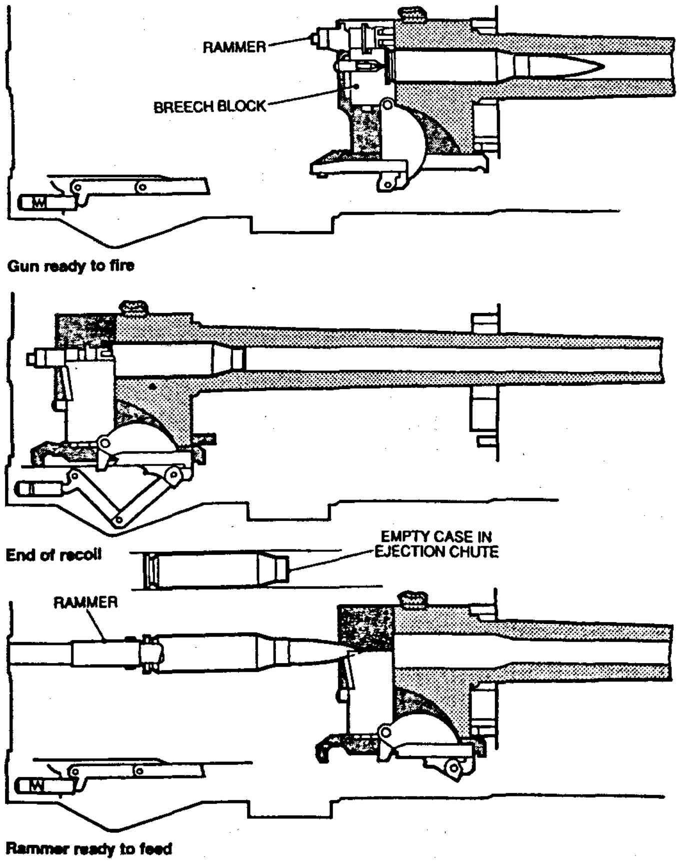


Fig 7.3 Long Recoil Operation - RARDEN 30mm Cannon

The live round is 285.75mm long so the total recoil of the barrel is only 44.65mm greater than the round length. Since the body of the gun does not recoil, it can be seen that this design produces a gun of remarkably short inboard length that is of great value in a fighting vehicle. It should also be noted that since the recoil is nearly completed before the breech slides open, there is little problem from toxic fumes that have had ample time to disperse. Any remaining in the case cannot emerge from the gun body that is virtually sealed off from the crew compartment.

Short Recoil

In a short recoil operated weapon the barrel and breech block are detached after a very short travel. This distance is much less than that required to allow feeding, but enough to ensure that the chamber pressure has dropped to a safe level. After unlocking occurs, the barrel will only move back a very short distance and then it is either stopped or returned to its fully run out position. The bolt continues its rearward movement under its own momentum that will frequently be increased mechanically by the use of an accelerator. The bolt movement will be sufficiently prolonged to produce an opening large enough for the insertion of an unfired cartridge and then the bolt will be driven forward to carry out the functions of feeding, loading and locking. Where the barrel has previously been stopped at the end of its rearward movement, the bolt energy will suffice to drive it forward to the firing position. The essential elements of a gun working on the short recoil system are shown in Fig. 7.4.

Components

The essential components of a short recoil operated system are the bolt, the locking system, an accelerator, a barrel stop and the springs required to return the barrel and breech block to the forward position. In the diagrammatic representation shown in Fig 7.4 the barrel returns to the fully run out position as soon as separation occurs. In modern weapons, this is the usual arrangement but in some older weapons such as the Browning machine gun, designed in 1905, the barrel is held to the rear until the breech block comes forward on the feed stroke.

The Cycle of Operations

The short recoil cycle starts with a round in the chamber and with the bolt locked to the barrel (see Fig 7.4.A). When firing takes place the gas pressure which drives the projectile up the bore forces the breech block rearwards. The breech block recoils within the body of the gun pulling the barrel back with it. As in long recoil the acceleration is controlled by the mass of the recoiling parts. After about 6mm of free travel in a rifle calibre gun, the breech block can be unlocked because the pressure has by then dropped to a safe level (see Fig 7.4.B). Shortly after the breech block has been unlocked from the barrel, the

latter contacts the accelerator. There are several different forms of accelerator but the type shown in Fig. 7.4 is the lever type which is the most common. This is illustrated in more detail in the figures that follow. The barrel extension first contacts the lever at its extremity and as the barrel recoils further to the rear the lever rotates and the point of contact between the barrel extension and the lever moves progressively closer to the lever pivot thus increasing the velocity ratio.

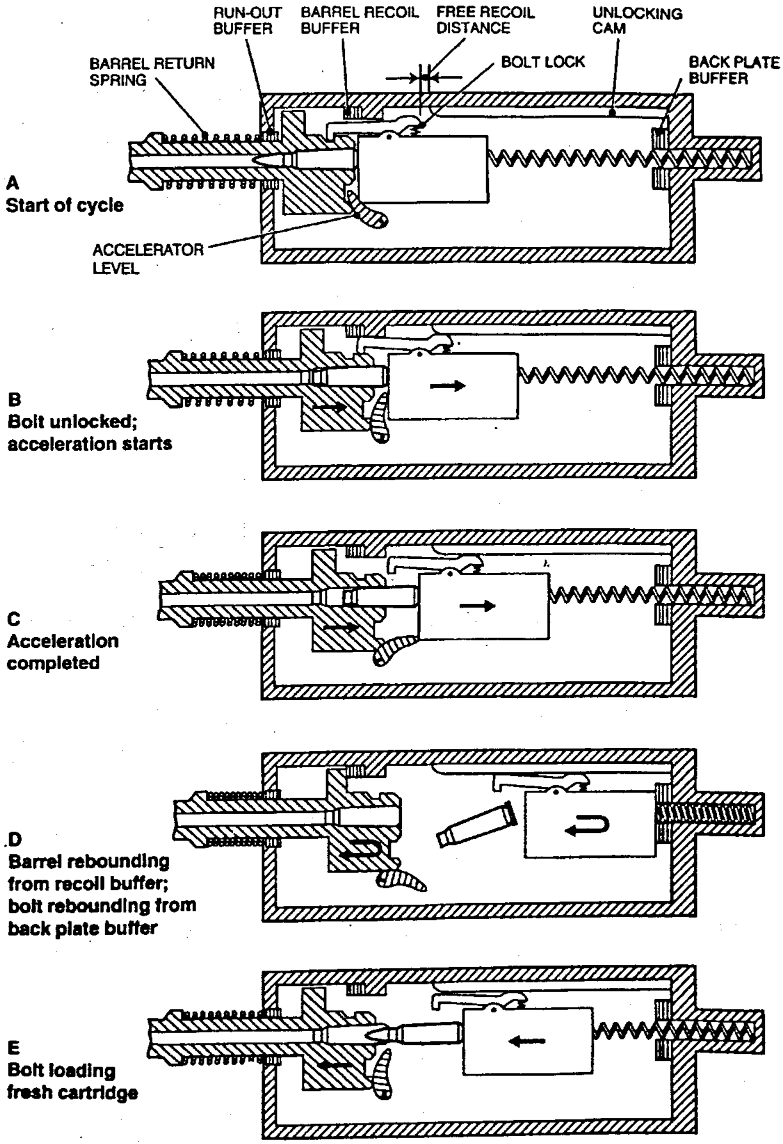


Fig 7.4 Elements of Short Recoil System - Diagrammatic

After the bolt has been fully accelerated, the barrel is brought to a halt. According to the design the barrel may be latched in this position or, as is more usual in modern design, driven forward again by its own spring. If the bolt has opened early enough its rearward velocity will be increased by blow back action and this, plus the accelerator effect, will give it enough energy to travel back far enough to allow sufficient space to feed the next round in. The empty case is extracted from the chamber and then ejected from the gun. The backward motion of the bolt compresses the return spring. This spring has to store only enough energy to drive the bolt forward when it is held to the rear by the sear prior to firing the first round. It is therefore a light spring and allows the bolt to travel throughout its recoil motion at a high velocity. The bolt then strikes the back plate buffer and this gives the forward velocity needed for feeding and chambering the next round. The coefficient of restitution of this buffer is less than unity and so some bolt velocity is lost at rebound. During the feed stroke the bolt is assisted by the return spring which, by supplying energy to overcome the friction losses caused by the feeding a round from the belt and chambering, allows the bolt to maintain a high forward velocity. The round is chambered whilst the barrel still has a forward movement and the round is fired before the barrel comes to rest in many designs. In heavier guns this is extremely valuable because the shock of contact as the barrel runs out is cushioned by the backward impulse imparted by the burning propellant.

Short Recoil Design Features

The short recoil system, when well designed, can produce a very high cyclic rate of fire. The German General Purpose Machine Gun MG 42 designed in World War II, now to be found in 7.62x51mm NATO as MG 3, is a good example. Its cyclic rate is 1200 rounds per minute. This high rate of fire comes from three factors:

- The high recoil velocity of the barrel and bolt at the time of unlocking.
- Blow back assistance.
- Accelerator effect.

The high recoil velocity at unlocking comes from the impulse produced by the chamber pressure. From the conservation of momentum, the rearward momentum of barrel and bolt will equal that of the bullet and gases. The lighter the combined weight of the barrel and breech block, the faster they will recoil.

In order to produce sustained fire the barrel should be massive to cope with the heat input and will therefore be heavy. The barrel, barrel extension, bolt head and locking device are all subjected to the force resulting from the high gas pressure and must therefore be strong and consequently heavy. These heavy parts cannot be accelerated at the rate required to produce a high rate

of fire and it becomes necessary to incorporate an additional source of energy to accelerate the barrel and bolt. This takes the form of a recoil intensifier or as it is often called a muzzle booster. A typical muzzle booster is shown in Fig. 7.5.

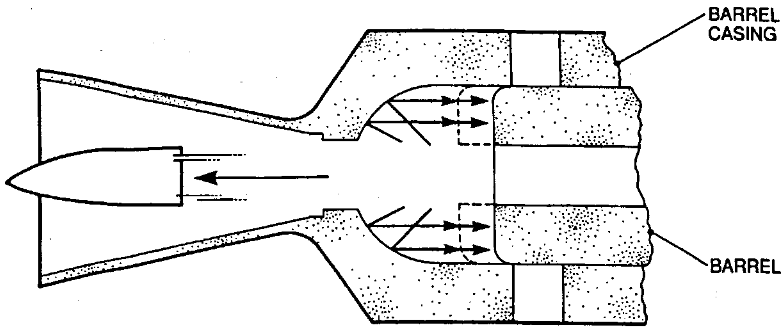


Fig 7.5 Recoil Intensifier - 7.62mm German MG3, GPMG

A casing that is non-recoiling surrounds the barrel. This casing is formed into an expansion chamber beyond the muzzle. When the bullet is passing through the exit to this expansion chamber, the gases following it build up a pressure at the muzzle that drives the barrel back. This increases the recoil velocity of the barrel and breech block just before unlocking occurs and thus the energy available to be transferred by the accelerator to the bolt is increased.

The next point to consider is the additional velocity given to the bolt by blow back action after the bolt is unlocked from the barrel. This effect in a short recoil operated gun is very similar to the action in a delayed blow back system. The principal factor affecting the selection of the time of opening the breech is the allowable movement of the cartridge case in the chamber during the action of the residual gas pressure. Effective blow back action depends on the free movement of the cartridge case in the chamber and this cannot take place if the case is binding to the chamber wall. If breech opening is delayed until the reduced gas pressure allows the cartridge case to return to its original dimensions, there will be no effective blow back action. However, since the breech is opened by the recoil action the design can incorporate a device to produce "initial extraction" to free the case from the chamber. When this feature is incorporated in the unlocking mechanism, the bolt is not unlocked completely at first but a slow powerful leverage is applied which slightly withdraws the bolt face causing the taper of the cartridge case to break free of the chamber wall. There is no way in which this initial extraction can be supplied in a blow back operated gun as the case is pushing the bolt back, whereas in a recoil operated gun the bolt can initially move away from the barrel and unseat the case. Thereafter the freed case can push the bolt back and accelerate it.

Blow back action has already been considered previously. It is sufficient to say here that the weight of the breech block and the time of unlocking must be so selected that the amount of case emerging unsupported from the chamber does not exceed that which can withstand the internal pressure without rupturing. This is generally taken as about 5.2 MN/m^2.

The third factor controlling the bolt velocity is the accelerator. The accelerator should only come into action after the full benefit has been gained from the bolt velocity at unlocking (including the bonus from the recoil intensifier) and from the blow back action.

The design of the accelerator itself is quite a complex matter. It must act smoothly and transfer energy from the moving parts to the bolt without shock or friction. The action of the accelerator can only last a few ms and if the transfer is not effected smoothly there will be hammering of the mating parts, deformation and frequent breakages. The fundamental requirements are therefore simplicity, reliability, strength and smoothness in operation. The velocity ratio achieved between barrel and bolt depends on the dimensions of the accelerator. It is not possible to use the accelerator to bring the barrel to a complete halt and thus the system can never be 100% efficient. In a well designed accelerator the velocity ratio can be 4:1 as in the Heckler & Koch roller system.

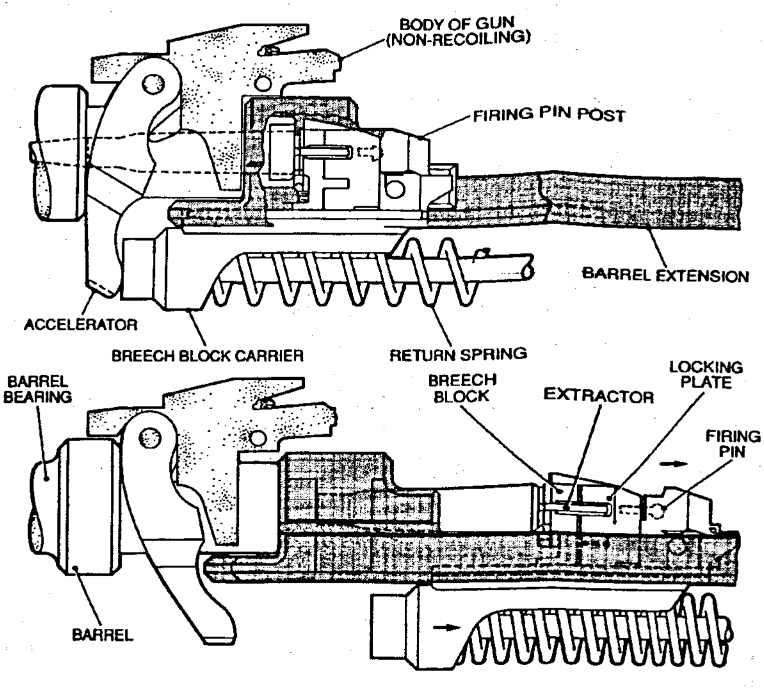


Fig 7.6 The Accelerator in the US 0.5in M85 HMG

The M 85 HMG at Fig. 7.6 shows the way in which the three requirements of bolt velocity at unlocking, blow back assistance and accelerator action can be met. The bolt is very small and light and thus to some extent offsets the massive barrel required. The breech opens early for blow back action. The accelerator is well designed and virtually brings the barrel to rest thus producing maximum energy transfer.

Examples of Recoil Operation

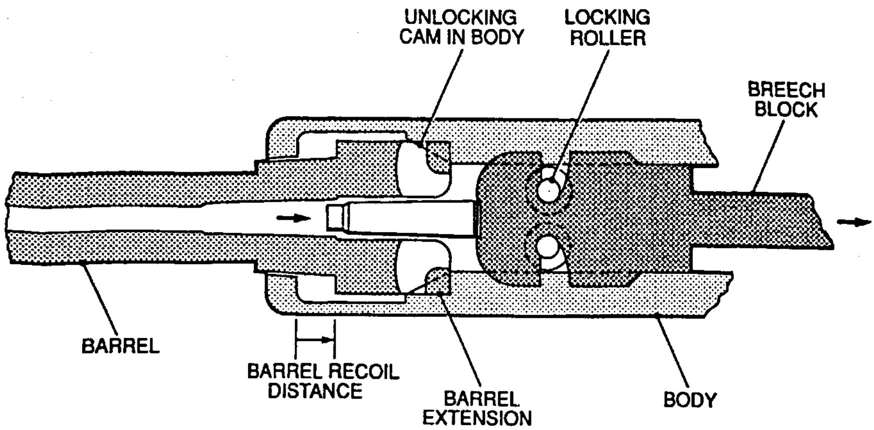


Fig 7.7 Short Recoil Operation - German MG3, GPMG

The German General Purpose Machine Gun MG 3 (shown in Fig.7.7) is undoubtedly one of the most efficient sustained fire machine guns produced. When the cartridge is fired, the breech block and barrel recoil together for slightly less than 6mm. During this short free period of free travel, the recoil intensifier accelerates their movement. The locking rollers are then forced inwards and the differential action caused by the variation in angle between the slots cut in the barrel extension and those in the head of the bolt, cause the bolt to be accelerated relative to the barrel. The bolt is given blow back assistance as it moves through the open portion of the barrel extension and is accelerated rapidly back. There is a substantial steel coil buffer that drives it forward with the minimum of loss, and feeding and chambering occur. The anvil holds the locking rollers into the undercut portion of their slot until the bolt head enters the barrel extension, when they are forced outwards to lock the bolt head in the extensions. The anvil can then pass through, driving the firing pin into the cartridge primer and thus firing the chambered round.

This weapon also features an interesting method of producing alternative rates of fire. There are three ways in which the rate of fire can be controlled:

- By varying the volume of the expansion chamber of the recoil intensifier and thus varying the rearward velocity of the unlocked barrel and bolt.

When the pistol is ready for firing, the round is chambered, locking lugs on the top surface of the barrel are engaged in recesses cut into the slide and the locking cam is over the locking shoulder. When the trigger is operated, the hammer drives the firing pin into the cap and the bullet starts to move up the bore. The breech block that is integral with the slide moves back in recoil and a lug attached below the barrel rides over a locking shoulder in the body. After a short period of free recoil during which the bullet leaves the barrel and the pressure drops the shoulder is engaged by an unlocking cam and the rear end of the barrel is drawn down. This unlocks the barrel from the slide and brings it to rest. The slide continues to the rear under its own momentum, drawing the case out of the chamber which is then ejected. On the feeding stroke the slide comes forward lifting the barrel and locking takes place. This system is simple, reliable and safe and produces a sturdy weapon. Due to the pivoting motion of the barrel it is necessary to have a clearance on the front barrel bearing and as a result wear takes place at the muzzle that results in a comparatively short accuracy life.

The USA .45 Colt functions on exactly the same principles but has a link to carry out the tilting and unlocking of the barrel.

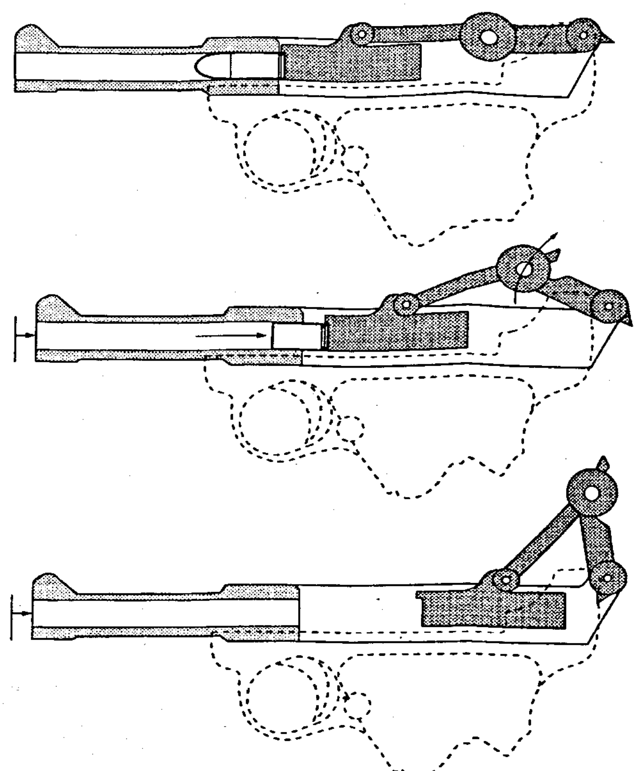


Fig 7.10 Application of Recoil Operation - Luger Pistol

The German Luger pistol (see Fig.7.10) is also recoil operated but the application of the principle is somewhat different. Here the barrel recoils back along its axis and no tilting occurs. The breech block reciprocates along the same axis and there is no slide. The round is in the chamber during the ready period. When the firing pin strikes the cap the bullet moves down the bore and there is a period of free travel of the barrel locked to the breech block until the toggle joint is broken and the breech block unlocked. This method of breech locking, although somewhat more complicated and expensive to produce, does have the advantage that the barrel motion is purely linear, there is no tilting of the barrel and accuracy life is much longer.

Summary of Factors Affecting Recoil Operation

Lack of Energy

In rifle calibre, short recoil operated, machine guns there is a lack of energy available to carry out the cycle of operations. The total energy available for recoil is only about 0.1% of the energy in the propellant whereas muzzle blast which can be used to produce gas operation is about 40% i.e. 400 times as great. This means that recoil intensifiers, accelerators, and a very efficient buffer must be used to make the most of what energy is available. From this it follows that there is a very small reserve of energy to allow the gun to function under adverse conditions, or in elevation or depression. Similarly there is little energy available to lift a long length of belt up to the gun.

Weight Distribution

In short recoil operated weapons the energy to carry out the cycle of operations is imparted to the block by:

- Its initial velocity when separation from the barrel occurs.
- Blow back action.
- The accelerator transferring energy from the barrel to the bolt.

Design Limitations

From this it follows that:

- Both barrel and breech block must be as light as possible to achieve a high velocity before separation.
- The breech block must be as light as possible to get maximum acceleration from the blow back action.

- The breech block/barrel weight ratio must be as small as possible to get the maximum benefit from the accelerator.

In general, both bolt and barrel should be light but practical considerations of strength, heating and wear restrict the amount by which the barrel can be reduced. Designers therefore tend to concentrate on reducing the bolt weight to a minimum compatible with the strength required to carry out the necessary tactical role.

Accuracy

The barrel moves backwards and forwards and must be accurately controlled. This leads to heavy, costly bearings which demand close manufacturing tolerances and produce problems of differential expansion as the barrel heats up. Since the barrel reciprocates, the foresight is generally attached to the barrel casing or body. It can be argued that, for a weapon with more than one barrel, it should be possible to carry out zeroing on the barrel so that the replacement of a new barrel by a worn one will not radically effect the mean point of impact (mpi).

Cooling

Cooling can be achieved by having a massive barrel that acts as a heat sink. It can also be obtained from changing the barrel. Both methods are in use with short recoil operated guns. The control of the barrel position is important when it recoils but once that problem is mastered recoil operated guns lend themselves particularly well to rapid barrel changing. Once the bolt has been withdrawn to the rear to unlock it from the barrel, the barrel can readily be withdrawn backwards. It should be noted however that if the barrel does not go forward under its own spring when separated from the bolt, barrel change can become complicated.

Barrel Withdrawal

The withdrawal of the barrel backward is very advantageous. In a purely ground role the firer or another crew member is not exposed as much as when the barrel goes forward for removal; but inside an armoured fighting vehicle where the barrel protrudes through the mantlet, rearward withdrawal simplifies barrel changes immensely.

Fouling

The recoil operated gun, unlike either the blow back or gas operated weapon is not prone to stoppages due to fouling. The recoil intensifier has to be cleaned but this is the only area where accumulation of fouling occurs.

✓

Fumes

The amount of fumes coming out of the breech with the cartridge case de
on the rate of fire. The earlier the breech opens and the greater the amo
blow back assistance, the greater the volume of toxic fumes. For this r
short recoil operated tank machine guns generally fire at a cyclic rate of
600 rounds/minute. The MG 3 fires at its slow rate in this role and the
fire of the USA tank machine gun, the M73, is designed specifically to
the rate below its full potential. Thus the fume problem is less with a
operated gun than with a gas or blow back operated gun.

8.
Gas Operation

Basic Principles

In all automatic weapons, with the exception of those powered externally, the fundamental source of the operating energy is the pressure created by the expanding propellant gases. This is true whether the gun is blow back, recoil or gas operated. However the term "gas operation" is reserved for a particular type of operating system in which the force derived from the propellant gases is applied in a particular way. The barrel of the gun acts as an expansion chamber and the pressure varies along the barrel as the projectile passes. Thus gas at any pressure varying from that at the chamber to that at the muzzle, can be drawn off at will. It was stated in Chapter 4 that some 40% of the energy contained within the propellant is ejected at the muzzle in the form of muzzle blast. This energy provides a useful source of power to operate a fully automatic system and weapons using this are known as "gas operated". It should be noted that the energy required for the efficient functioning of the cycle of operations is largely obtained from that which would otherwise be wasted at the muzzle and therefore there is little effect on the velocity imparted to the bullet. A muzzle trap system has therefore attracted attention in the past.

Gas that is tapped off in the barrel to operate a piston is contained between the piston and cylinder and even if the cylinder is vented the gas will not escape until the bullet has left the muzzle.

The factors involved in tapping the gas off near the muzzle are:

- Minimum effect on the ballistics.

- Low pressure gas requires a large volume to perform the required task. Muzzle gases contain a lot of solid carbon which has been re-sublimated.

The factors involved in tapping the gas off near the breech are:

- High pressure gas – therefore parts involved must be robust.

- Short delay before gas is available: this is an advantage where a high rate of fire is required.

- Hot gases will erode the gas hole in the barrel.

These factors generally lead to a compromise in which the gas is tapped off some 177-305 mm from the muzzle in a rifle or LMG. This gives the power required without either unacceptable erosion or carboning of components.

As already stated, a gas system of operation can employ many types of gas actuated devices. Although the functional characteristics of a weapon will largely depend on the particular type of device used, all gas operated guns are basically similar in their operation. Since some form of gas piston is by far the most common actuating device, it will be used here to illustrate the principle involved.

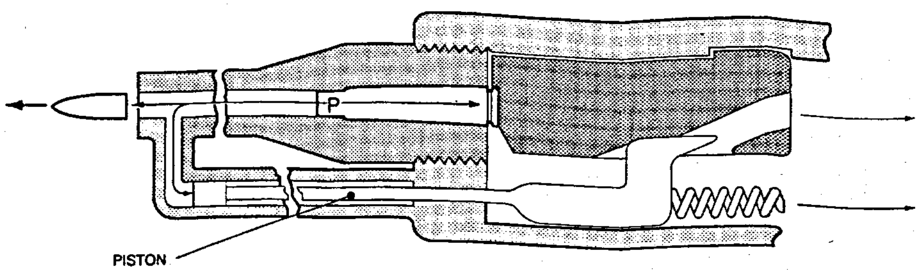


Fig 8.1 Typical Gas Operated Gun

Fig. 8.1 shows the essential elements of a gun operated by the gas system. These elements consist of a piston, a bolt, an arrangement for locking the bolt and later unlocking it, a return spring for returning the piston and bolt to the forward position and, behind the return spring, a back plate (not shown) which will often house a buffer.

In large calibres such as 20mm, the recoil forces are large and it is frequently necessary to allow either the barrel and bolt to recoil within the gun body and as well as, or in addition to, allowing the entire gun to recoil within a buffered cradle. This requires additional springs to return the barrel and the entire gun, to the run out position.

Cycle of Operation

The operating cycle of a typical gas operated gun is straightforward and occurs as follows:

- The cycle starts with the round chambered and the bolt locked either to the barrel extension or to the body of the gun. When the cartridge is fired, the gas pressure drives the projectile forward and, at the same time, those parts of the weapon designed to recoil will move back. In the great majority of cases there will be no arrangement for the barrel to move within the body, so the entire weapon will recoil.

- The time at which the projectile passes the port in the barrel will depend on the location of the port and will generally be about 0.75-1.5ms after cap initiation for a light machine gun and up to 2.0ms for a 20mm gun. As soon as the bullet passes the port the gas will enter the cylinder and pressure will build up. Due to the throttling effect the cylinder pressure will approximate to one third of the barrel pressure during the period that the impulse is applied to the piston. There will always be a period of free travel of the piston before the unlocking of the bolt commences. This will allow the bore pressure to drop to a safe operating limit; in most cases the bullet will be well clear of the muzzle when unlocking occurs.

- After unlocking occurs the residual bore pressure continues to exert a force on the piston and also provides some blow back action on the cartridge case. After the unlocking of the bolt, the piston accelerates the bolt, and the piston and bolt move rearward together. The normal cycle of operations is carried out.

- In those cases where the recoiling mass of barrel and bolt has an independent cycle, the barrel return spring will restore the recoiling masses to the run out position.

- In those cases where the bolt and barrel recoil within the body the bolt will have acquired a rearward velocity before unlocking takes place and so the bolt velocity will be high. If there is no recoil movement of the barrel and bolt which is the usual case in rifles, LMGs and GPMGs, then immediately after unlocking there will be an acceleration of the bolt as the piston drives it rearwards and any blow back action is felt. Unless care is taken in the design this acceleration can be violent and result ultimately in undue wear of the piston and/or bolt and possibly failure. It is common modern practice to use a roller on the piston post to reduce wear on this member when the piston post is used to rotate the bolt into and out of the locked position.

- The bolt extracts the fired case which is ejected from the gun and throughout the backward movement of the bolt the return spring stores energy. When the breech block ceases its rearward travel its kinetic energy has been transferred to potential energy stored in the spring and is available to drive the bolt forward to complete the functions of feeding, chambering and locking.

- In larger calibre small arms the barrel will have recoiled before unlocking takes place. It will be restored to the run out, or battery position, by a return spring. Many designs will hold up this forward motion so that the gun actually fires with the barrel and bolt moving forward. This serves two purposes. It reduces the shock transmitted to the barrel and body of the gun as the barrel completes its run out; it also ensures that a large proportion of the firing impulse is used to stop forward movement of the barrel

and thus reduce the amount of impulse available to drive the recoiling parts back.

Types of Gas Operation

Over the years the design of gas operated infantry guns has crystallized into three distinct categories. These are:

- Long stroke pistons.
- Short stroke pistons.
- Direct gas action.

Long Stroke

The long stroke piston is permanently attached to the breech block and controls its position and velocity throughout the cycle. There are many examples of this type of gas operation. The illustration in Fig. 8.2 is that of the British L7A1, GPMG.

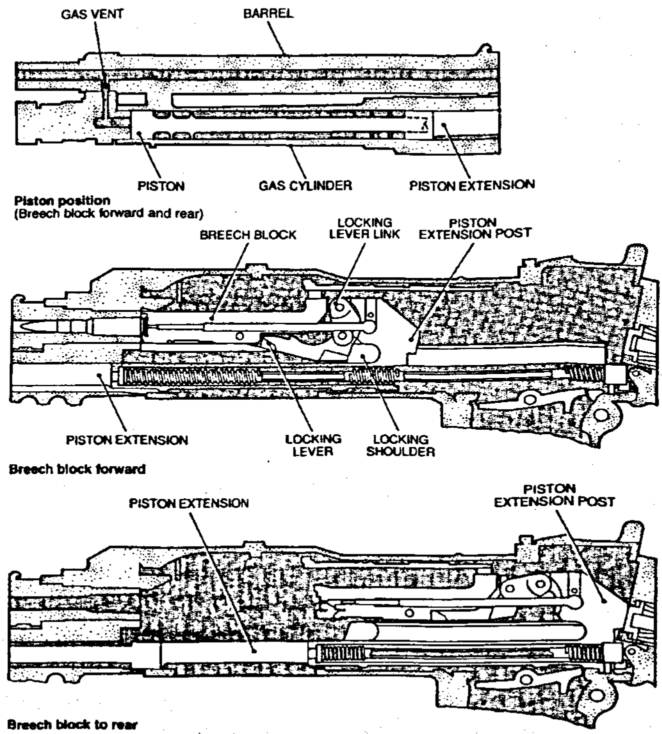


Fig 8.2 Long Stroke Piston - L7A1, GPMG

When the bullet passes the gas port, the gas enters the cylinder and the piston is driven back. There is a period during which the piston motion has no effect on the bolt which remains fully locked. The locking lever link during this period of mechanical safety is approaching the vertical position and until this is achieved there is no force exerted on the locking lever and it remains firmly in contact with the locking shoulder in the body. Thereafter the locking lever is progressively lifted out of engagement with the locking shoulder until unlocking is completed. The bolt is then carried to the rear by the piston, extracting and ejecting the spent case. The return spring is aligned with the piston and assists the piston forward on rebound from the back plate buffer. The piston thus controls the position and velocity of the bolt throughout the operating cycle.

By careful design in choosing the correct position and size of the gas port, the correct area of the piston head and the appropriate mass of the piston, the correct piston velocity and energy can be obtained to provide a chosen rate of fire for any given gas pressure.

In early designs the gas port was located at the bottom of one of the rifling grooves to ensure that material was not stripped from the cupro-nickel or gilding metal envelope which would block off the gas hole. In many modern designs the positioning of the gas hole relative to the rifling, is entirely at random. For example, in the British L1A1 rifle or L7A2 GPMG, the hole will be drilled at a fixed distance from the breech face. It is usual to locate the gas cylinder above or below the barrel but there are exceptions. The French aircraft cannon, the AmE621 for example, has two gas holes, one on each side of the barrel, with two cylinders similarly located.

The long stroke piston is the type of design most commonly employed in gas operated LMGs and GPMGs. The bolt is always correctly positioned relative to the position of the piston and the method of locking is always controlled by the piston.

Types of Cylinder for Long Stroke

Vented Gas Pistons

The piston may move inside a closed, vented or open cylinder. With the vented or open cylinders the gas pressure can only be sustained until the piston reaches the vents or the open end of the cylinder. Thereafter the kinetic energy of the piston and bolt carries out the cycle of operations. The reason for a vented cylinder is to allow the gases and the carbon particles contained in the gases to be blown clear of the gun. An example of a vented cylinder is the BREN gun.

Open

The open cylinder allows the entire piston to emerge and so the cylinder is then completely open to the atmosphere and the fumes and carbon particles are completely dissipated. The 1939-45 tank machine gun, the BESA, is also an example of this. After about an inch of travel, the piston emerges from the cylinder.

Closed

The closed cylinder is rarely met in modern weapons. There are some adaptations of the Garand rifle still in service and these have a closed cylinder. The Lewis gun was another example.

Cupped

The piston head is not always a male member moving in a female cylinder. Sometimes the gas is passed through a spigot into a hollow cupped head on the piston which envelopes the spigot. The piston may have a sufficiently deeply cupped head to remain over the spigot throughout the full movement of the bolt as in the German SL Rifle M43 or, more usually, the piston head will leave the spigot after a short rearwards travel, to allow the gases to vent. An example of this is shown in Fig. 8.3 where the Russian RPD LMG is illustrated.

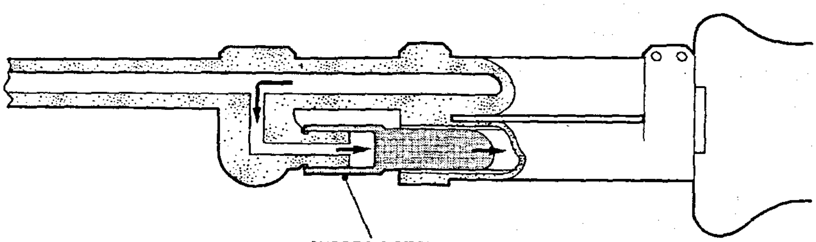


Fig 8.3 Cupped Piston, Long Stroke - Russian RPD LMG

Short Stroke Pistons

In the short stroke piston system of gas operation, gas is tapped off at some point along the bore and bled into a cylinder. A piston is given an impulsive blow that drives it rearwards either coming into direct contact with the breech block carrier or driving back an operating rod that is permanently attached to the bolt.

The piston imparts energy to the breech mechanism and is then returned by its own spring to the forward position. Thus the piston is not attached to the breech block, and once having delivered energy to the breech block it follows an independent cycle.

An example of the first type, where the piston delivers an impulsive blow to the bolt carrier is shown in Fig 8.4. This is the Belgian FN-FAL Rifle from which the British L1A1 SLR was derived. The gas pressure drives back the piston which, after a brief travel, contacts the bolt carrier or slide. The bolt carrier is driven back and then picks up the bolt, unlocks it from the body of the gun and carries it rearward. The process of extraction takes place as the case is pulled out of the chamber. As soon as the piston has transferred its energy to the bolt carrier assembly, the greater momentum of the latter carries it rearwards and the piston spring drives the piston forward again. Thus the piston is in contact with the bolt carrier for only about one third of the bolt travel.

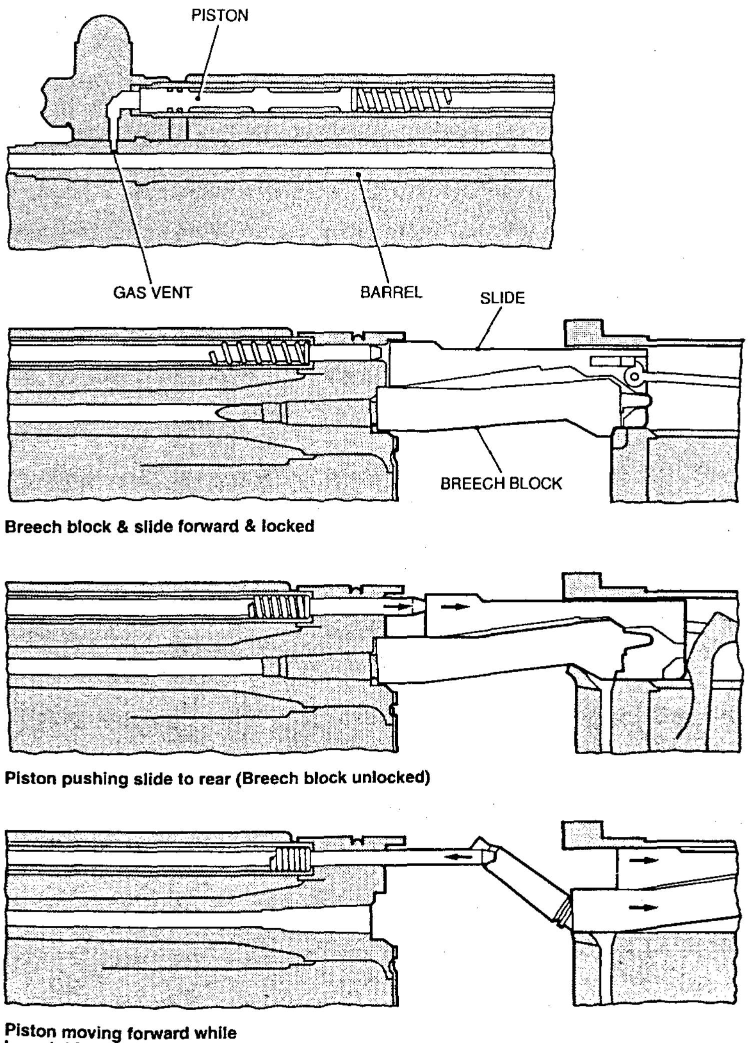


Fig 8.4 Short Stroke Piston - FN-FAL Rifle

An example of the use of an actuating rod to operate the bolt assembly itself is shown in Fig 8.5. Here the piston travel is only about 6mm: the piston itself is a short stroke tappet which delivers an impulsive blow to the actuating rod, which is sufficiently energized to control the bolt throughout its cycle. The completion of this short movement by the piston seals off the gas, which eventually finds its way back into the bore and disappears with the rest of the residual fumes. The actuating rod returns to the forward position ready for the next round and re-positions the piston.

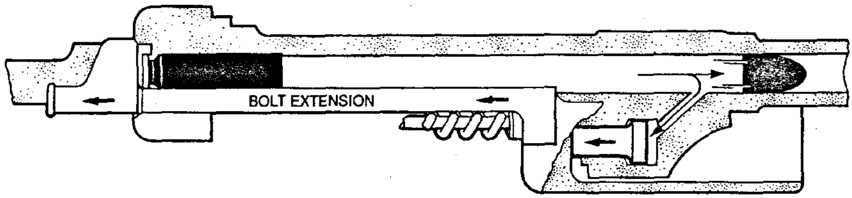


Fig 8.5 Short Stroke Piston – American M1 Carbine

In general, short stroke pistons produce a weight saving; but to obtain the necessary energy the shorter the stroke the nearer the breech the gas must be tapped off.

The short stroke piston system has been used in the past with a piston wrapped round the barrel instead of being located in the usual position above or below. This results in a symmetrical thrust around the barrel axis which, it is claimed, helps to reduce the turning moment on firing. Fig 8.6 shows an illustration of this taken from the Czechoslovakian Vz 52

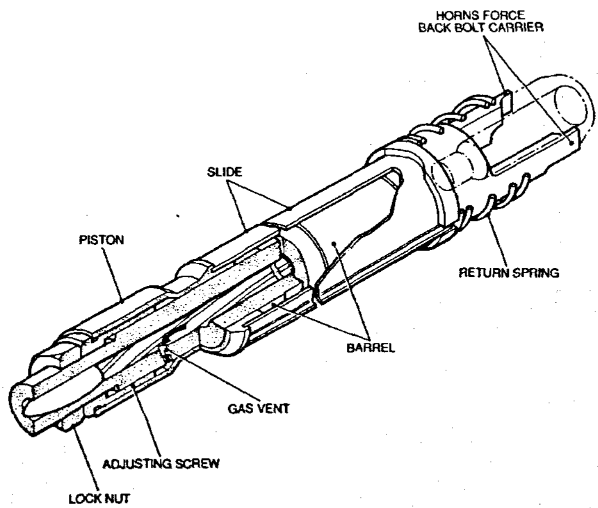


Fig 8.6 Wrap Around Piston - Czech SL Rifle, 7.62mm Vz 52

The gas is tapped off in the normal way and builds up pressure in a chamber formed between the barrel and the piston which is in the form of a sleeve. The sleeve is forced back and the rear end applies an impulsive blow to the bolt carrier which, after a short free travel, unlocks the bolt and carries it backwards. The chamber volume can be varied as required to produce a higher or lower pressure, but this necessitates stripping the fore end, undoing the lock nut and varying the position of the adjusting screw which is not a quick process in the field.

Neither the German rifle, the G 41, nor the Czech rifle, both of which used this type of piston arrangement were successful. The barrel was bulky and a heavy weapon resulted. When the barrel was hot there was differential expansion between it and the piston sleeve, leading to a slowing down of the working parts and, eventually, stoppages.

Direct Gas Action

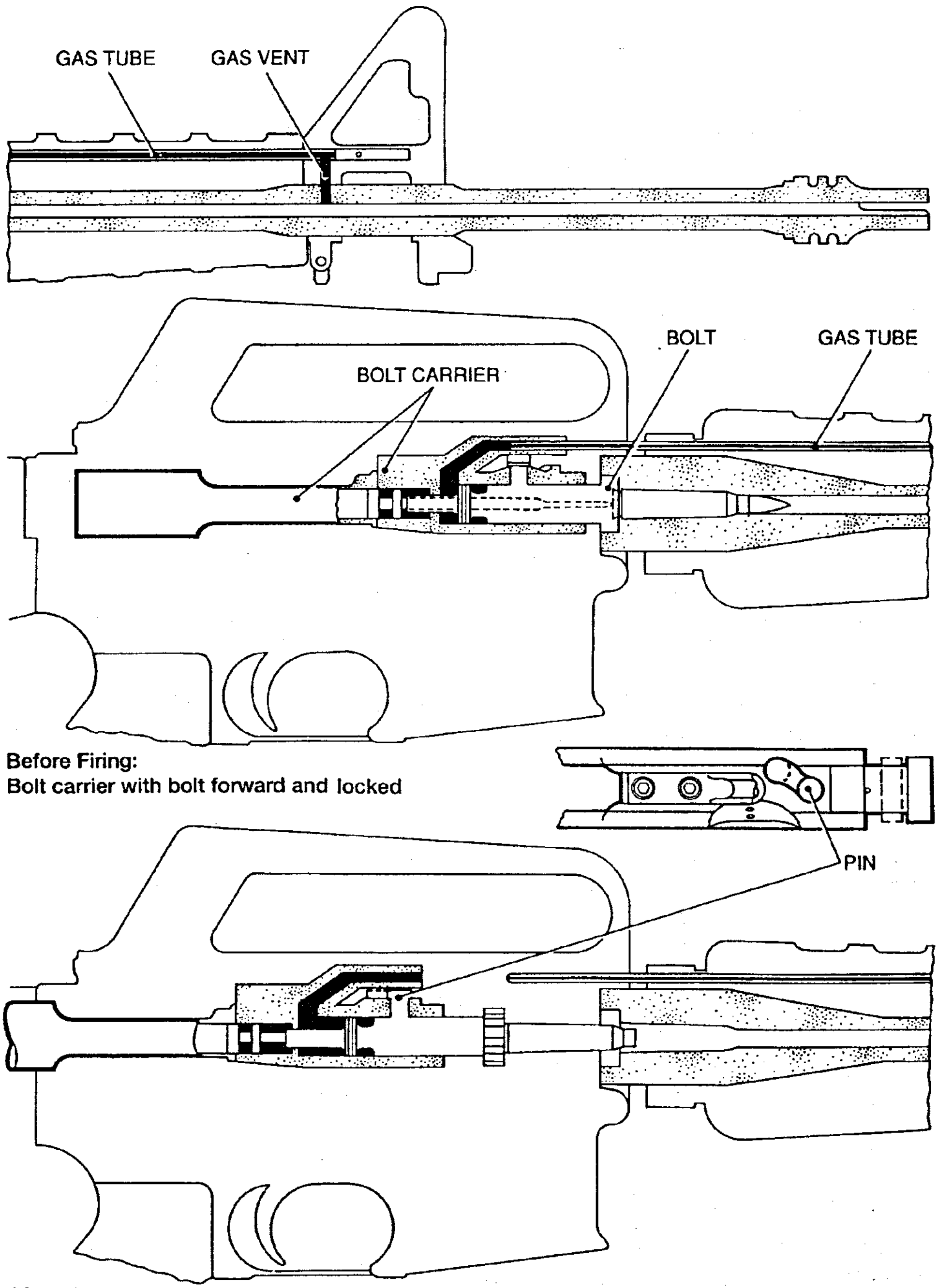
This is the system in which gas is tapped from the barrel and taken along a tube to act directly on the breech system to unlock it. This system was used on the Madsen - Ljungman, the French MAS 44, the Egyptian Hakim rifle and is now used in the American Armalite rifle, the AR-15 or M16, which is illustrated in Fig 8.7.

The gas is tapped off some 140mm from the muzzle and led back via a stainless steel tube into a chamber between the bolt head and the bolt carrier. The gas expands in this chamber and drives back the bolt carrier. The bolt head is locked into the barrel extension and cannot move. As the carrier moves back a curved cam slot cut in its upper surface rotates a pin, attached to the bolt head, about the longitudinal axis of the bolt and unlocking of the bolt head is brought about. The carrier has already acquired a considerable momentum and this, plus the blow back action on the breech face, causes the bolt to move rearwards extracting the empty case. No gas regulator is fitted.

This system is light, simple and cheap. The main drawback is that carbon particles are deposited all round the breech head and these become hard on cooling. Thus a weapon which is not frequently cleaned is liable to incur stoppages. To reduce stoppages the M16 has a chromium plated chamber and barrel.

Control of the Operating Energy

There is a great deal of energy available to drive a gas operated gun. It is desirable to control the amount of energy supplied and to vary it according to the requirements of the occasion. A clean gun firing under ideal conditions requires a much smaller energy supply than a hot dirty gun operating in a desert environment, where sand adds significantly to the friction forces to



Before Firing:
Bolt carrier with bolt forward and locked

After Firing:
Bolt carrier to rear; bolt rotated and unlocked

Fig 8.7 Direct Gas Action - Rifle M16

produce a stoppage. Similarly a gun firing continuously down a hill will require more operating energy than one firing on the level. It is for these reasons that most modern section weapons are gas operated.

There are several ways of controlling the rate of flow of the gas to the operating system. These are described in more detail in the following paragraphs and are:

- A variable size gas track.
- A control varying the amount of gas exhausted to atmosphere.
- A constant volume valve which shuts off the gas supply after a pre-determined movement of the piston.
- A variable expansion volume at the head of the piston.

This variation of gas force will also allow a variation in the rate of fire. The more gas to the piston head the greater the rate at which it will accelerate backwards and the shorter the time of the cycle of operations. This is the basis of the FN system of controlling the rate of fire.

It should also be noted that insufficient gas will frequently drive the piston back sufficiently to allow extraction, ejection and feed, but will not give enough backward movement to enable the bent to ride past the sear. Thus when the trigger is released and the sear rises, the gun will not stop firing and a runaway gun results.

The Variable Gas Track

This system is one of the oldest and is certainly the simplest to operate. A gas regulator carries a number of tracks each of different size. Fig 8.8 shows the BREN LMG.

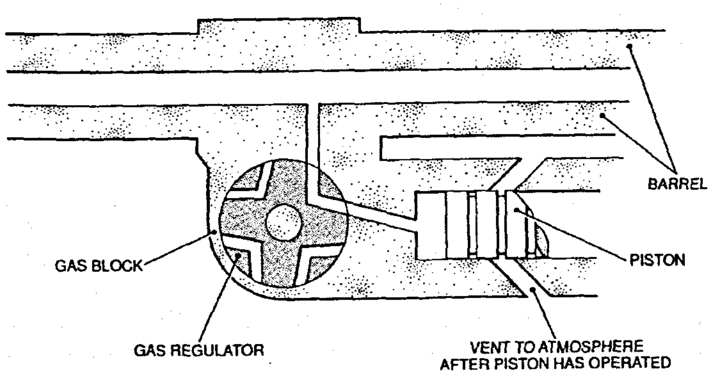


Fig 8.8 Variable Gas Track - BREN, LMG

A similar system is used in the Russian medium machine gun the Goryunov M 43 shown in Fig 8.9. Here there are only three tracks, which are not drilled through the gas block as in the case of the BREN, but are grooved on the outside of the regulator which fits into a sleeve in the block. In both of these examples the gunner varies the energy supply to the piston head by rotating the regulator within the gas block to align a different sized track with the barrel vent.

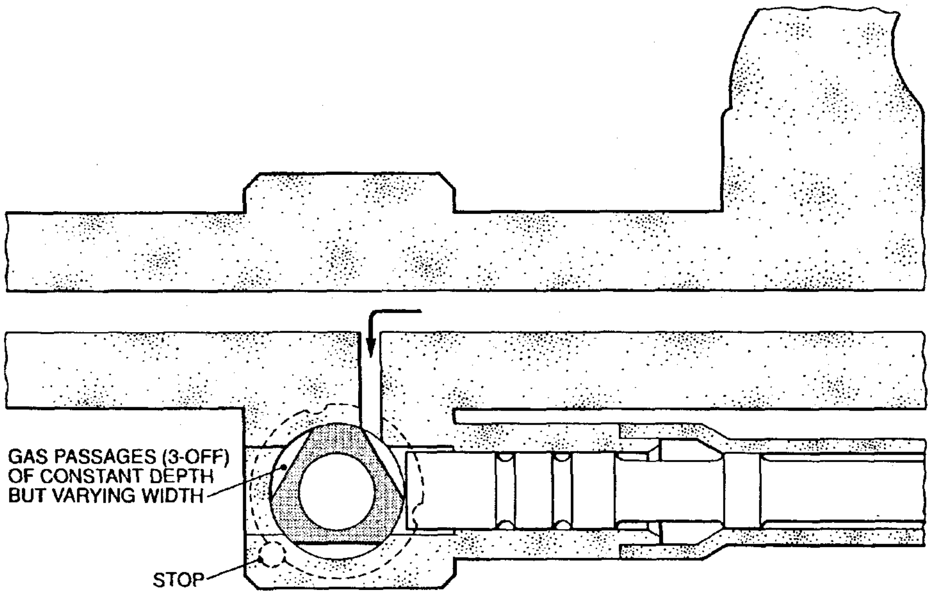


Fig 8.9 Variable Gas Track - Goryunov M43 MMG

Variable Exhaust to Atmosphere

This system at Fig. 8.10 utilizes the basic principle that more energy is available than will generally be required. A fairly large hole drilled in the barrel allows gas to pass through the gas block and into an expansion chamber. Some of the gas then escapes through a series of radial holes around the chamber into the atmosphere. The remainder of the gas is used to drive back the piston.

When the gun requires more power as it gets hotter and dirtier the gas regulator is rotated to close off the radial holes and so less gas is exhausted to the atmosphere and more is available to operate the cycle. This method is employed very successfully in the FN rifles the FAL and CAL, and in their machine gun the MAG, from which the British GPMG the L7A2 is derived . This system will also allow the rate of fire to be varied from about 700 to 1100 rounds per minute.

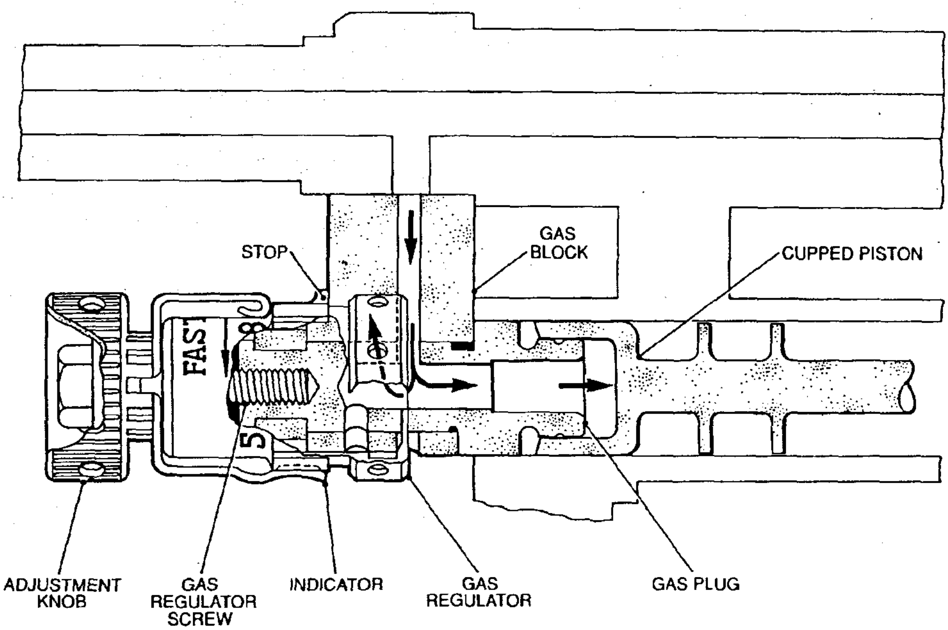


Fig 8.10 Exhaust to Atmosphere System - L7A2, GPMG

Constant Volume System

In this system the gas passes through the barrel wall and then through the wall of the piston head. It expands inside the cup of the piston and drives the piston rearwards. When the piston has moved back a little way the hole in the piston wall is no longer aligned with the vent in the barrel and so no further gas enters. This is a self-regulating system and so no control by the firer is required. A current variation of this system is employed in the USA M 60 GPMG shown in Fig 8.11. A hollow piston has a number of holes with a groove connecting them. The gas can enter any of these holes so that the piston does not have to be indexed relative to the barrel vent. The hollow piston moves back a short way and transmits its energy to an operating rod which is itself permanently attached to the bolt. Thus, although the piston has a short stroke action, the bolt is controlled by the operating rod.

The primary object of this system of gas control is to enable a weapon to fire various natures of ammunition which themselves will have different gas pressures at the barrel vent. This means that both ball rounds with lead cores and armour piercing rounds of solid construction and higher velocity, can be digested by the gun. The valve shuts off the gas supply when a certain amount of energy has been taken in and the system is sometimes referred to as a "constant energy system". This is really a misnomer because the amount of energy the gun requires to operate is itself not constant but varies with the

increased frictional forces produced by dirt, heat, lifting an ammunition belt of differing length and when firing in elevation or depression. Thus if the resistance to piston motion is high, the gun tends to slow down, although more energy will be tapped off due to the sluggish piston motion.

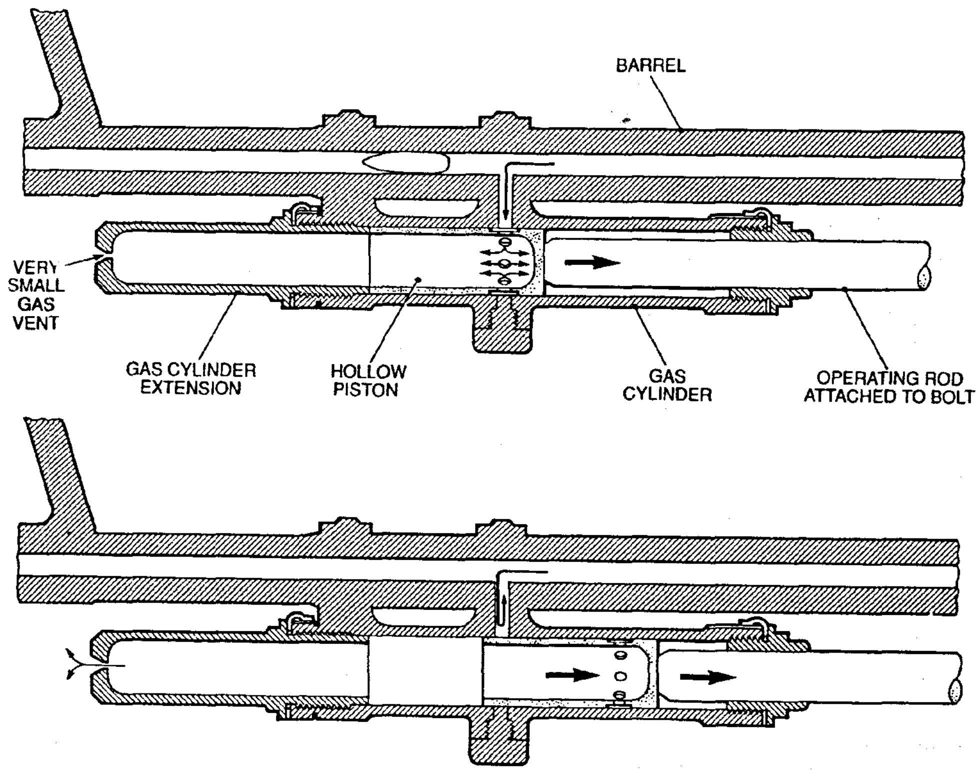


Fig 8.11 Constant Volume Regulator - USA M60 GPMG

Variable Expansion Volume

The variable expansion volume system allows variation of the pressure in the cylinder by adjustment of the volume of the space in which the gas expands. In its simplest form shown in Fig. 8.12, the firer can rotate a plug at the front of the cylinder and, by so doing, the space in front of the piston head is varied in volume. This produces a pressure variation at will.

The system is not found in modern weapons but was used in earlier machine guns such as the Hotchkiss. In a conventional layout the firer, or more usually

a second crew member, has to reach right forward to apply a tool to the adjusting screw and this means he is exposed to enemy fire.

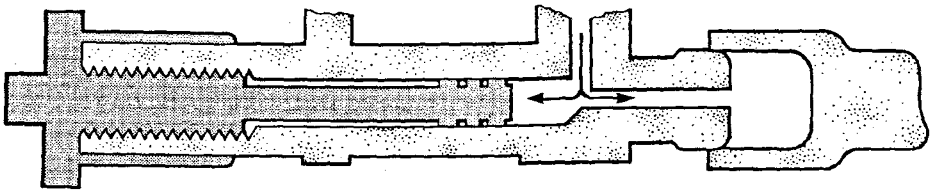


Fig 8.12 Variable Expansion Chamber

Control of the Cyclic Rate of Fire

It is not normal in modern weapons to have a tactical requirement to vary the rate of fire although this has been a feature of older weapons. Often a gas operated gun, as it heats up, will tend to produce a cyclic rate which will be higher than necessary, so it will tend to damage the working parts and back plate buffer, as well as unnecessarily increasing the expenditure of ammunition. To prevent this a 'compensation' hole, which allows more gas to escape at high temperature, is fitted.

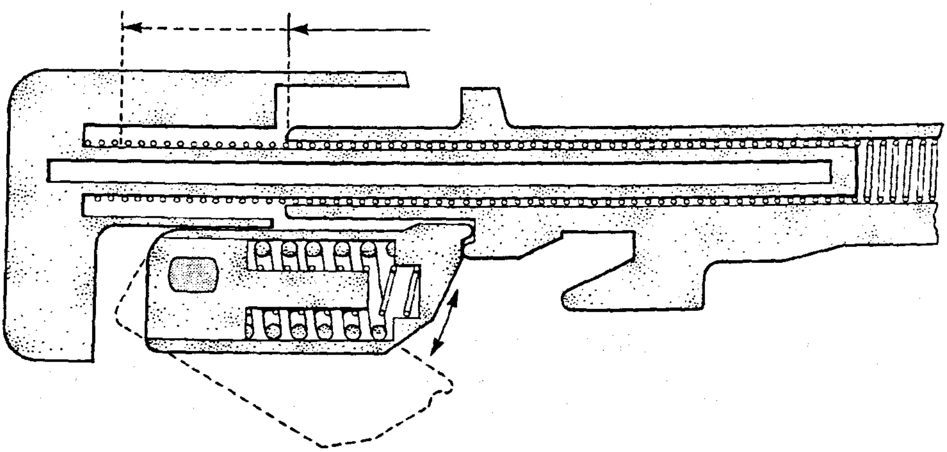


Fig 8.13 Variable Stroke Length - Czech Model 37

To reduce the rate of fire some device is incorporated to hold up the working parts when they are in the rearward position. There have been many such devices. Some are hydraulic, some incorporate a watchmaker's escapement and some use an inertia pellet. One is shown in Fig. 8.13. This was embodied in the Czech 7.92mm tank machine gun, the model 37, which was taken into British service as the BESA. Here a spring buffered block was rotated, at will,

into the path of the piston extension and the overrun was shortened. This shortened stroke and the effect of the spring, reduced the time taken for each cycle.

Advantages of Gas Operation

Flexibility

The principal advantage of gas operation, which is not available to blow back and recoil operated weapons, is its flexibility. When the weapon is clean and firing under ideal conditions, the impulse required to operate the cycle is small. With a dirty gun firing in depression or elevation, far more power is required. The gas regulator caters for this requirement and the gas operated gun has proved its worth in deserts, swamps and under all conditions where frictional forces can become excessive. The gas regulator can also be used to increase the power when an excessive length of belt has to be lifted.

Light Weight

The selection of the correct gas pressure enables the working parts to be lightly constructed and so, as a rule, the gas operated gun will be lighter than recoil or blow back operated weapons.

Rate of Fire

A gas operated gun can be designed to produce a very high rate of fire. By tapping off gas close to the chamber and unlocking the breech whilst the pressure is still quite high, thus obtaining blow back assistance, the cycle can be cut down to a minimum period of time.

Accuracy

The working parts are light, there is little change in the position of the centre of gravity and the vibrations caused by locking are minimized. The barrel is fixed relative to the body so a gas operated gun can be extremely accurate.

Disadvantages of Gas Operation

Fumes

All gas operated guns throw out fumes and are therefore not basically suitable for use in an enclosed space like a tank turret. This is shown in the British L8A1 tank machine gun where the gas regulator system has been modified and a special tube incorporated to remove fumes into the exit gas stream.

Erosion

Hot gases erode the gas vent. In time this leads to an increased gas flow as well as local irregularity in the bore.

Carbon

The gas contains carbon which will eventually clog up the system unless special arrangements are incorporated in the design, such as vented cylinders and exhausting systems.

Barrel Change

All gas operated guns incorporating a piston have slow barrel changes. There is usually a spigot connection between the barrel and the gas cylinder which in practice means that the barrel must be pushed forward to remove it from the gun. This is a disadvantage in the field and particularly so inside a tank turret where the whole gun must be withdrawn into the turret to enable the barrel to be drawn off in a forward direction. Both recoil and blow back operated machine guns have a distinct advantage in this respect. But one must remember that blow back operation causes toxic fume problems in enclosed spaces.

9. External Power Operation

Basic Principles

There is nothing new in the idea behind this system where no use is made of any available propellant power. Indeed bolt action rifles, all revolvers and the original 'Machine Guns' used power provided by the firer himself to reload. All that has been added recently is an electrical motor to replace the human. It has been suggested that it was the American helicopter pilots in Vietnam who hastened this development because they took exception to having to get out and clear weapon stoppages!

There should be inherent advantages to an externally powered system such as the Chain Gun:

- Once loaded, it can be operated remotely.
- Due to the dwell time that can be built into the system, extremely low levels of toxic fumes can be expected in a turret.
- Better reliability can be expected so long as a suitable power source is available. Rounds unfired for any reason are cycled through the gun and ejected.

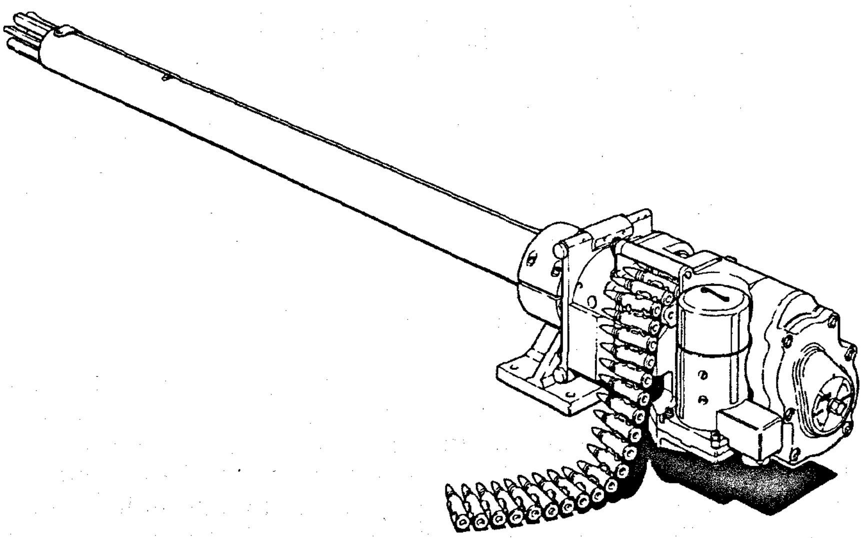


Fig 9.1 L94A1 Chain Gun

There are however some disadvantages as well:

- Without power the gun can be fired using a crank handle but at under 30 rpm. In an AFV turret in combat, this effectively means no power = no gun.
- It is not sensible to dismount this sort of weapon. Chemical or mechanical hang fires become a potential problem and may cause breech explosions.

Revolver Action

This method is highly regarded by those who depend on reliable first time and subsequent operation of their handgun. Unlike a pistol, where a round which fails to fire for any reason, must be extracted by recocking the weapon, a revolver only requires a repulling of the trigger. Nor does such a weapon use a separate magazine with its inherent snags of possible damage and mal-feed. In handguns the revolver does suffer from a number of drawbacks with few ready to use rounds and probable slow reload time.

Another area where this type of action is likely to be found is in re-loadable weapons for HE, Baton and other riot dispersal natures of ammunition, for example ARWEN.

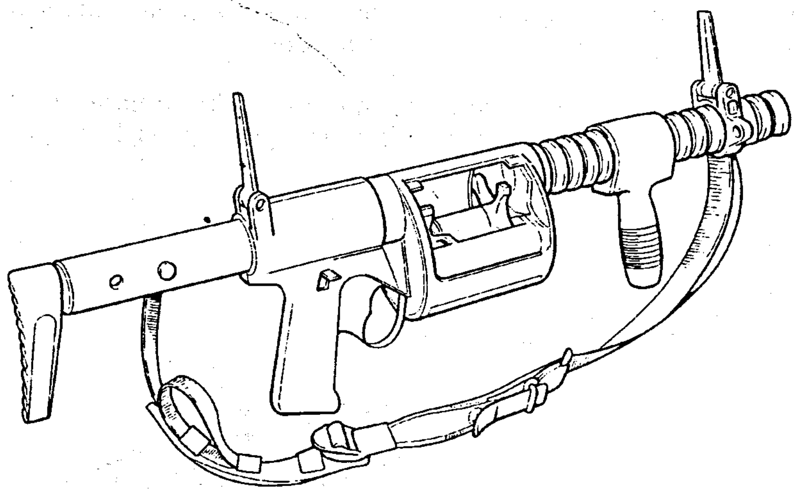


Fig 9.2 Royal Ordnance Five Shot Anti-riot ARWEN 37

A further area where revolver systems can be found is where very high rates of fire are required. Foremost among such weapons are the numerous different multi-barrelled GATLING Guns. In this case the barrels, complete with chambers, are rotated. The particular method of ammunition feed is explained in a later chapter. Each barrel fires about 1000 rpm so that the ultimate rate of fire is dependent on the number of barrels.

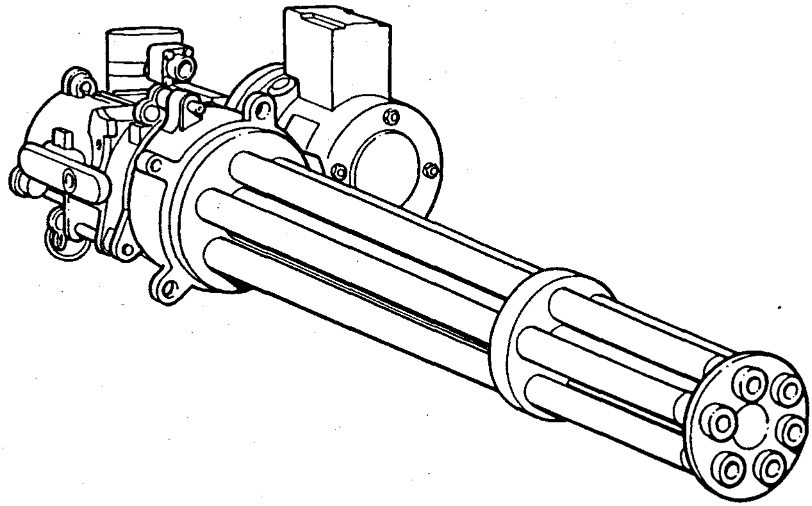


Fig 9.3 Six Barrel 5.56mm Gatling

However aircraft cannon such as Mauser and Aden also utilise this revolver system, where just like a handgun, the chambers rotate to fire out of a single barrel. The power is provided by the propellant in the cartridge and is a gas operating system. They are only mentioned here due to the 'revolver system' of operation. Rates of fire between 1200 and 1850 rpm can be achieved.

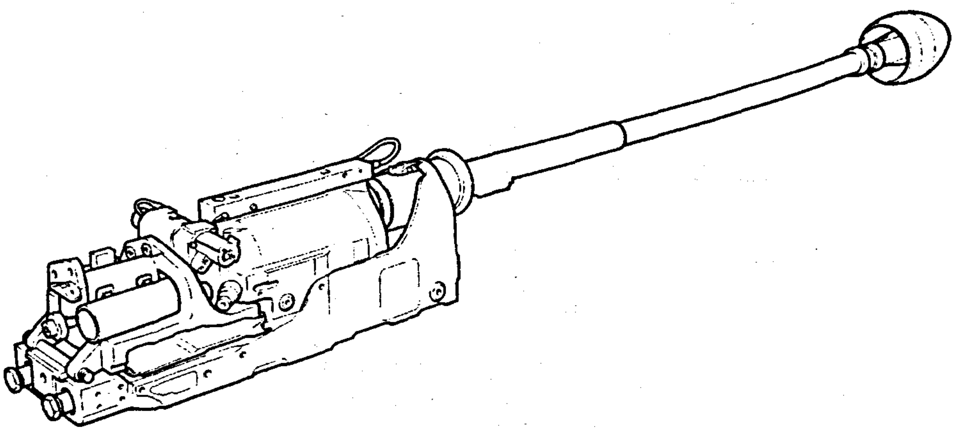


Fig 9.4 25mm ADEN Cannon for Harrier GR7

Chain Gun Cycle of Operations

The Chain Gun gets its name from the endless chain loop at the heart of the system. The chain is driven by a vertically installed electric motor that also drives the feed mechanism through a gear box. The chain follows a rectangular

path around sprockets at each corner as shown in the schematic below. The chain has a master link that connects to the feed, ram and ejection parts. It is the long dwell time (13ms from firing to unlock) that makes this such a good MG for turret mounting because the gas pressure in the barrel has long since returned to atmospheric. Any remaining toxic fumes are then more likely to be blown out by the over pressure in the turret. The cycle of operations is the same as for any MG. By varying the voltage fed to the motor, the rate of fire can be changed easily.

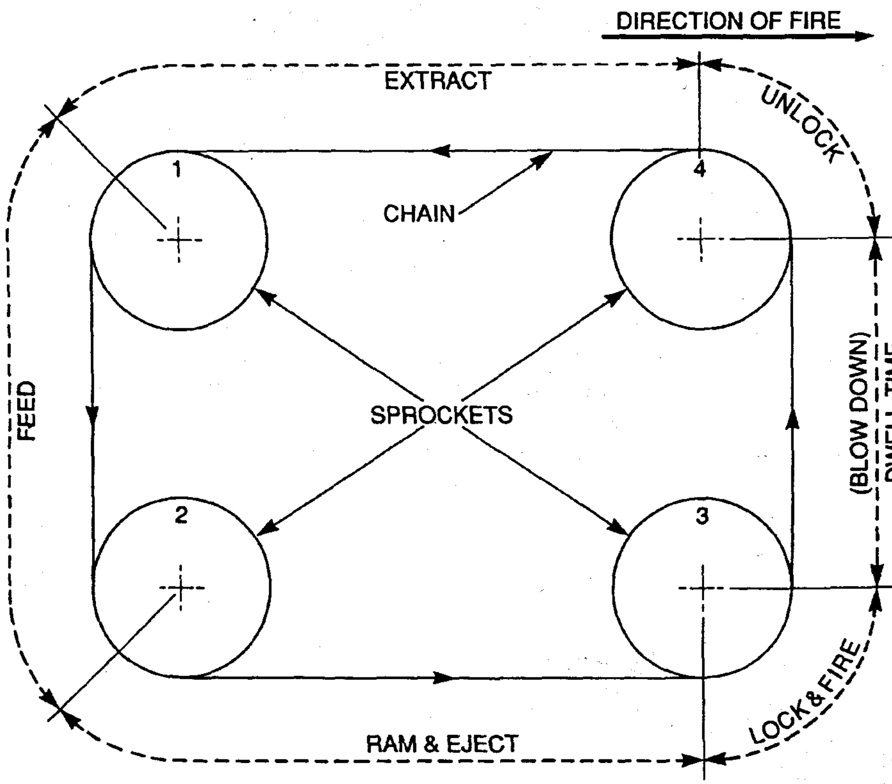


Fig 9.5 Chain Gun Cycle

The gun cycle continues after the trigger is released and always parks in the 'open' or safe position. This is achieved through a complex electrical control box. In the beginning the self-parking mechanism worked erratically and caused a number of 'cook offs', however this was rectified. At the time it was thought by some that the ammunition was to blame due to 'Hang Fire'. This idea was rather absurd because, in the proofing of hundreds of millions of rounds, very few, if any, 'Hang Fire' over 2ms has been observed, which is well under the 13ms dwell time.

A more comprehensive idea of the operation can be seen from Fig 9.6.

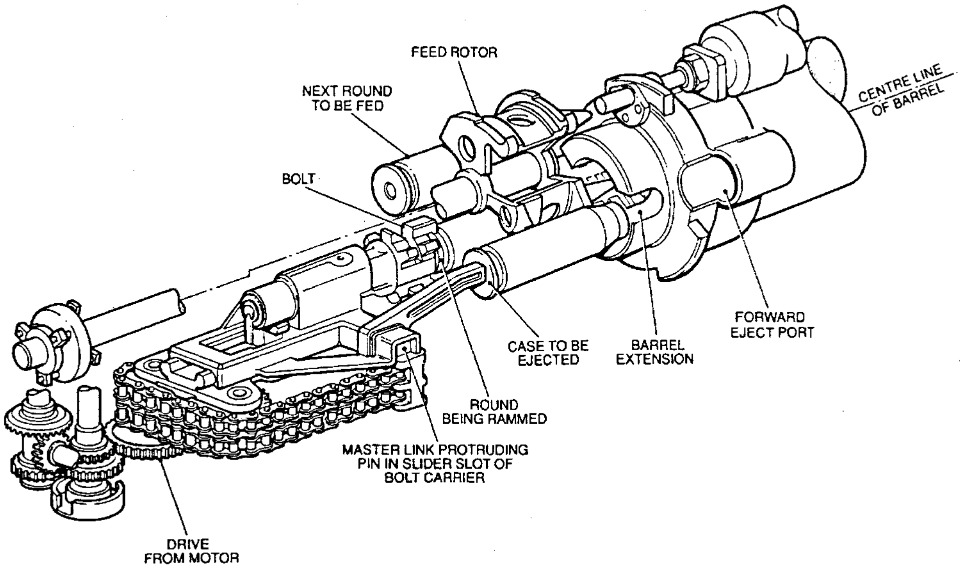


Fig 9.6 Chain Gun Principle

Yet another advantage found with this gun is the way the empty cartridge cases are ejected up a tube in the barrel shroud and thrown some 25m forward of the muzzle. This ensures that the brass cases do not interfere with any other system in the vehicle. Only the belt links need to be collected. These have a tendency to catch on each other and, if they 'ball up' in the throat of the collection chute, can and have caused stoppages.

The working parts make for a very compact inboard receiver, ideal for fighting vehicles. The top cover is also small and opens to the side. The whole receiver can be removed and taken to a more convenient place where it can be rectified. The barrel can be easily changed with the special tool. This does not disturb the alignment of the weapon zero or coaxial mounting. Feed and link ejection are both on the left side of the weapon.

The bolt is locked to the barrel extension by rotation of twin lugs moved through 45° by a cam. These lugs also form the twin fixed extractors. The firing pin cannot protrude until the bolt is locked in position.

The design of the Chain Gun lends itself to having the components contracted out to different manufacturers and then assembled on a production line, the same as motor cars.

The 7.62 x 51mm L94A1 version of the original Hughes Chain Gun was chosen as the coaxial VMMG for the British Infantry Armoured Fighting Vehicle, WARRIOR, and as the coaxial MG for the CHALLENGER 2 tank. It is likely to

become the standard British AFV coaxial MG for the foreseeable future. It is interesting to note that, although the chain gun was invented in America, it is not used on their Bradley APCs or Abrahms tanks as the coaxial MG.

10. Locking and Mechanical Safety

General

Modern rifles and machine guns operate at pressures in excess of 308 MPa and this is far more than the unsupported cartridge case can withstand. It is essential for the safety of the firer and to prevent damage to the weapon that the cartridge be fully supported, not only around the periphery but also at the base, whilst the internal pressure is high. The maximum permissible unsupported projection of a rifle calibre case whilst the pressure is of the order of 3.5 to 7MPa is not more than 3mm.

Definition

Mechanical safety is defined as that feature of design that ensures:

- A round cannot be fired until it is fully supported in the chamber.
- The support cannot be removed until the chamber pressure is at a safe level.

From this definition it follows that the design of the weapon must ensure that:

- The cap cannot be struck until such time as the round is completely within the chamber.
- Some suitable device is employed to provide support for the base of the round before the cap is initiated.
- A period of delay is incorporated to allow the pressure to drop to an acceptable level before the support to the base of the round starts to be removed.

Manually Operated Weapons

The requirements for mechanical safety differ between manually operated and automatic or self-loading weapons. In manually operated weapons it is sufficient to provide the necessary support to the round in the chamber and to ensure that there are no circumstances in which the round can be fired until this support is in position.

There is no requirement to provide any delay before the support is removed because it is physically impossible for any firer, regardless of how adept and practised, to remove the support before the bullet is well clear of the muzzle. For example, the period of time during which a bullet is in the barrel of a 7.62mm SL rifle is about 1.7ms after cap initiation. This period of time is far too short for the firer even to react and it is impossible for him to complete the process of unlocking in that time.

Automatic Weapons

The same level of safety is essential in automatic weapons. In addition there is the necessity to incorporate in the design some delay before the support to the case is removed to allow the bullet to leave the barrel and for the pressure to drop to a safe level. This will be one of the major tasks confronting the designer because it will conflict directly with any requirement to produce a high rate of fire. Obviously the dead time, whilst the breech remains closed and the pressure drops, will reduce the rate of fire.

Methods of Providing Mechanical Safety

There are two basic methods available to the designer dependent solely on the methods of operation chosen for his weapon. These are:

- For blow back operated weapons, an inertia or delayed opening breech block.
- For recoil and gas operated weapons, a positively locked breech.

Blow Back Operated Weapons

It is only in the great majority of small pistols of about .22in calibre where blow back is found. This method of operation is rarely met in military pistols or larger calibre weapons. The only noteworthy exceptions to this are the Russian 9mm pistols the Makarov (PM), the Stechkin (APS), and the Czech Skorpion (M-61). All of these fire a low powered round. Owing to the short barrel length and low powered cartridge the momentum level is low and it is sufficient to provide heavy working parts, the inertia of which must be overcome before the breech opens. It is usual to prolong the breech block and form a slide which passes round and over the barrel. This provides a grip for the initial cocking of the mechanism and allows a distribution of the mass to provide a reasonable balance.

Advanced Primer Ignition

In larger calibres, such as 20mm, it becomes essential to control the point at which cap initiation occurs. So mechanical safety before firing is produced by the positively controlled hammer which drives forward the firing pin only when

the round is in the correct position for firing. The Polsten gun illustrates this feature.

Blow Back with Delay

Mechanical safety before firing is obtained by ensuring that, until the lever or rollers are in position engaging in the body of the weapon, the firing pin cannot pass forward to strike the cap. An example of this is shown in Fig. 10.1 and is taken from the Swiss machine gun the SIG 710-3.

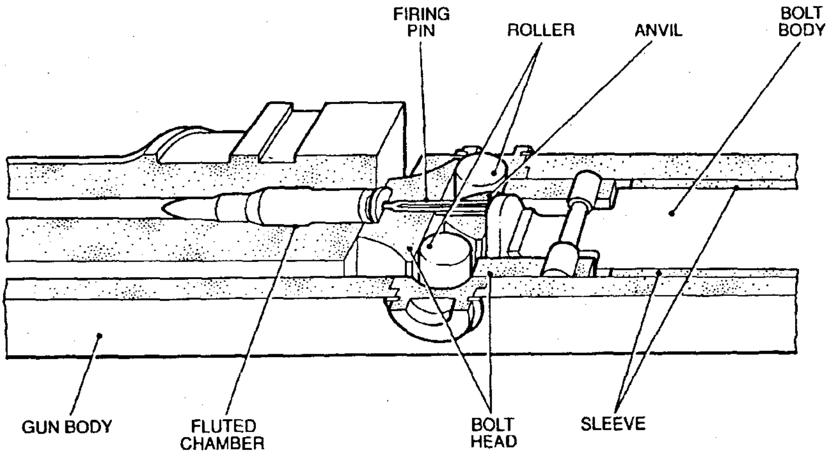


Fig 10.1 SIG 710-3 Mechanical Safety

It will be noted that the closing up of the bolt body to the bolt head will drive the firing pin forward, whilst at the same time positioning the bolt body ready to move back, when the firing impulse is applied to the bolt face. Mechanical safety after firing comes from the resistance offered to the rearward motion of the breech face, caused by blow back, provided by the differential action of the lever or rollers which impart a velocity to the bolt body. The bolt face moves back less than 3mm before the pressure drops to 7 MN/m^2

Blow Back with a Locked Breech

Here the mechanical delay both before and after firing depends on the locking system used and is the same as those used for recoil and gas operated guns and is described in the paragraphs that follow.

Breech Locking Systems

Locking is defined as that function of the mechanism that physically secures the bolt or breech block to the barrel. The purpose of locking the breech block or bolt to the barrel is to ensure that:

- The base of the case is fully supported before firing occurs.

- The bolt cannot be forced back or caused in any way to release the support afforded to the cartridge case whilst the pressure is high.

From the above definition it might be assumed that all forms of locking require a connection between bolt and barrel, but this is not so. In many cases the locking occurs between bolt and body but since the body is effectively connected to the barrel the result is the same.

In modern weapons the tendency is to lock the bolt directly onto the barrel extension. This has the advantage that the firing stresses are limited to the barrel, the barrel extension and bolt head; these are the only parts that need be proofed. Thus these parts are of high quality steel but the remainder of the bolt can be of lesser strength. The body of the weapon is not directly stressed at all and acts as a guide to the recoiling parts whilst providing a firm anchorage for the feed mechanism, trigger mechanism and other items.

The method of operation also has a direct bearing on the locking. A recoil operated weapon must be so designed that the barrel and bolt will recoil locked together within the body. Therefore the bolt obviously cannot be locked to the body in this method of operation. Even though locked, this is not sufficient to ensure mechanical safety. The designer must arrange his weapon in order that in no conceivable circumstances is it possible either for the cap to be struck before the cartridge is fully supported, or for the support to be withdrawn before the pressure has dropped to the level considered to be safe. Thus mechanical safety and locking can be considered not as separate factors, but together as an entity.

Methods of Locking

Over the years the hundreds of different methods of locking that have evolved have been grouped according to the type of weapon. These groups, summarised in table 10.1, will be discussed with the view to showing how mechanical safety is achieved in each type.

Table 10.1 Method of Locking with Weapon Type

Locking Method	Weapons
Rifles	
Hinged Breech Block	Martini Type
Rotating Bolt	Mauser & Lee Enfield
Automatic Weapons	
Toggle Joint	Maxim & Vickers MMGs

Locking Method	Weapons
Rotating Bolt	AK47, AK74, M16, SA80, AUG Steyr
Tilting Block	Guryunov M43, FN FAL, BREN, SLR
Sliding Block	US M73
Projecting Lugs	Russian RPD, UK EM2
Self-Loading Pistols	
Toggle Joint	Luger
Locking Lugs	Browning 9mm

Rifles

The rifle was the original small arm with a method of breech loading embodying a mechanism that allowed for continual loading and ejecting of rounds at will. With breech loading came the need to provide support to the base of the cartridge when it was in the chamber. This was originally achieved by a variation of the hinged breech block where the arc of rotation about a horizontal axis positively located it to the breech face and prevented any movement backwards once the block had been rotated into position.

It can be seen from the hinged block of the Martini action, shown below, that it cannot move back and it is prevented from rotating downwards by the provision of a strut which holds it up when the loading lever is in the closed position.

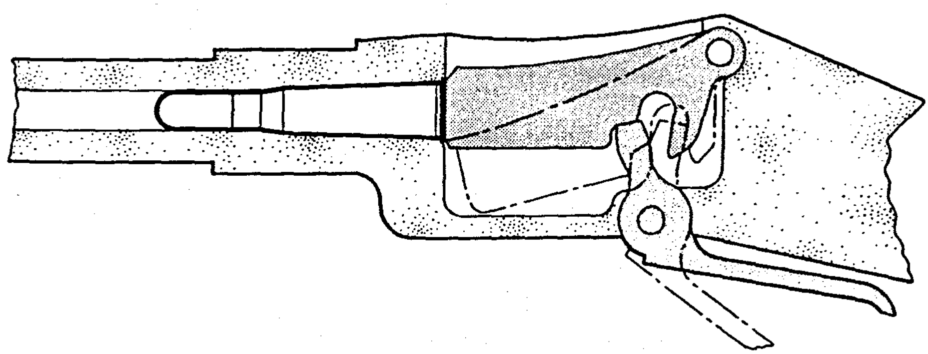


Fig 10.2 Hinged Block, Martini Rifle

Mechanical safety is achieved before firing by:

- The non-alignment of cap and striker until the bolt is closed.
- The curtailment of striker movement until the locking lever is in the fully closed position.

There is no requirement for any provision to delay breech opening because it is manually operated. There is insufficient time to operate the loading lever before the pressure has subsided. This type of breech action is very largely used in small bore competition rifles, such as the BSA International, but is only met in old pattern military rifles used in primitive communities.

Rotating Bolt

The Martini action fell into disfavour when magazine rifles became common and it was obviously better to feed the live round and extract the empty case using a bolt moving along the axis of the weapon. In general the bolt is rotated to lock and unlock the breech. There are one or two exceptions in which a pull on the bolt causes a block to rise from engagement in a locking recess in the body. There are also straight pull bolts, such as the Swiss Schmidt-Rubin and the Ross rifle, where the motion is used to cause a follower, moving in a cam groove in a sleeve, to rotate the sleeve which carries the locking portion of the bolt.

The three main types of rotating bolt mechanisms are shown below. All of these depend on rotating locking lugs into recesses in the rifle body, or the barrel extension, to lock the bolt, to close the breech and to support the base of the cartridge in the chamber.

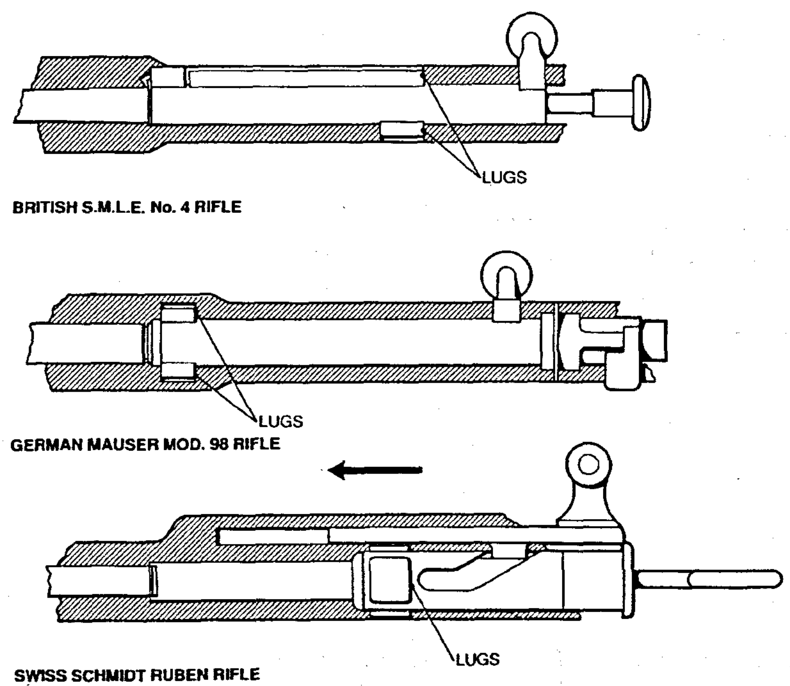


Fig 10.3 Rotating Bolt, Hand Operated

The first example in Fig. 10.3 is from the British No. 4 Rifle. It has a bolt basically identical with that of the original .303in Lee-Metford service rifle issued in 1888. The locking lugs are situated about two thirds of the way down the bolt, which simplifies design and manufacture and in addition ensures simple maintenance in the field. The locking lugs engage in recesses in the body so that the hooded extension to the barrel needed in the Mauser action (shown in the second illustration in fig 10.3) is not required. The distance the bolt must be withdrawn, only slightly, exceeds the length of an unfired round. The Mauser type forward locking lugs require the bolt to be withdrawn an inch further to the rear for extraction and loading, since the locking recesses are forward of the magazine. There are various factors which favour rear locking lugs and there are certain advantages possessed by a forward locking lug system. The locking lugs being to the rear, as in the No. 4 rifle, puts a very large amount of the bolt in compression on firing. The body is put into tension and so both bolt and body have a long stress path. Since the stress is the same in both rifles, with forward or rear locking lugs, and both can be said to be made of the same quality material, then the strain must be the same in each case. This means that the change of dimension of the bolt length with rear locking lugs is about four times as great as with forward locking lugs. This movement of the bolt within the body combines with the body change of dimension caused by tension to produce a movement between barrel and body which causes inaccuracy. The body is cut away on the right hand side to permit entry of the long locking lug and so a thickening up of the body is required to attempt to eliminate the bending of the body which occurs on the firing of each round. The shorter bolt movement aids rapid firing and allows the firer to actuate the bolt without moving his eye from the sights or the target. In the Mauser action the longer length of bolt movement makes this almost impossible. The bolt can be removed easily and the bolt and body can be readily cleaned. With the hooded extension used in the Mauser system, it is much more difficult to clean the body of the weapon, so the ingress of dirt makes stoppages more likely.

The advantages of the Mauser forward locking system are greater accuracy due to symmetrical support of the bolt in the body and a stronger, uniformly stressed, body. It is probably true to say that under competition conditions the Mauser action is preferable but on active service the rear locking system has advantages.

The third example in Fig. 10.3 shows the Swiss straight pull bolt. It was originally designed to simplify and speed the method of manipulation but it suffers from an excessively long bolt movement to the rear, which in practice reduces the number of aimed rounds that can be fired in a given period of time.

Automatic Weapons

During the time that the rotating bolt type of locking lug was being developed for the rifle, parallel work was being done on a locking system for a machine

gun. It is of course considerably more difficult to produce mechanical safety in a mechanism which has a cyclic rate of fire of, say, 600rpm, (i.e. 10 rounds each second or only 100ms between shots), than it is with a bolt operated rifle.

Toggle Joint

The toggle joint appeared in the Maxim machine gun and was inverted in the Vickers gun. The example below shows the principle of the toggle joint lock that was used in the British Vickers .303in Mk 1 MMG.

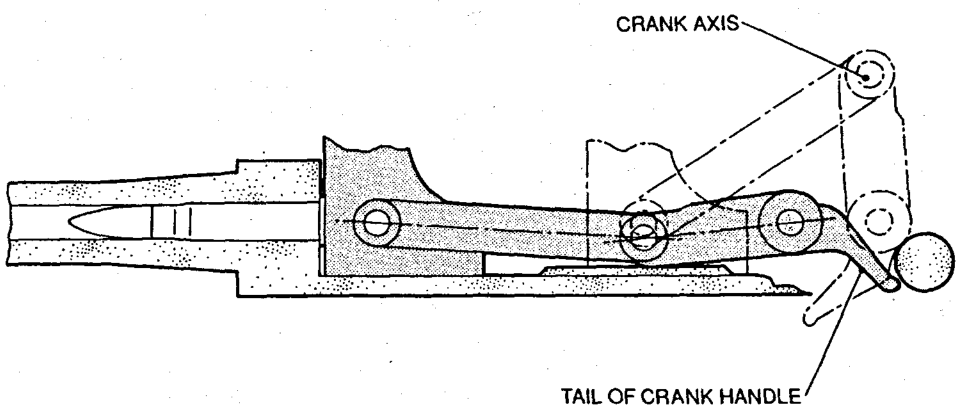


Fig 10.4 Toggle Joint Lock, Vickers Mk 1

The locking device has two arms. The longer one is pivoted in the breech block and the shorter one on the barrel extension. The two arms are jointed at the crank axis that floats freely. Breech locking is obtained by allowing the crank axis to drop below the line joining the axes on the breech block and the barrel extension. The crank axis is then supported on a shelf in the gun body. To unlock the toggle joint, an upward force is required at the crank axis; but since the crank axis has been dropped below the horizontal, all the firing forces tend to drive it downwards where it is fully supported and immobile. On firing, the breech block and barrel recoil together, until the tail of the crank handle comes into contact with a roller on the side of the breech casing. It can be seen from the diagram that this causes the crank axis to rise and rotate to the rear thus, breaking the toggle lock and retracting the breech block. The final backward movement of the breech block forces the barrel extension axis forward and thus the barrel is driven forward to its firing position. Mechanical safety is obtained because the weapon fires from a closed breech and all the trigger and firing mechanism is contained within the breech block. After the trigger is pulled the firing pin cannot go forward until a sear is released by the crank axis falling below the horizontal. Thus the completion of the locking fires the gun. After firing the barrel and breech block recoil together firmly locked for 6.3mm

until the tail of the crank meets the roller. The bullet by then has long left the muzzle and the pressure is down to a safe level. The concept of the toggle joint lock is employed in the Luger pistol and in principle it is precisely the same as that employed in the Vickers machine gun.

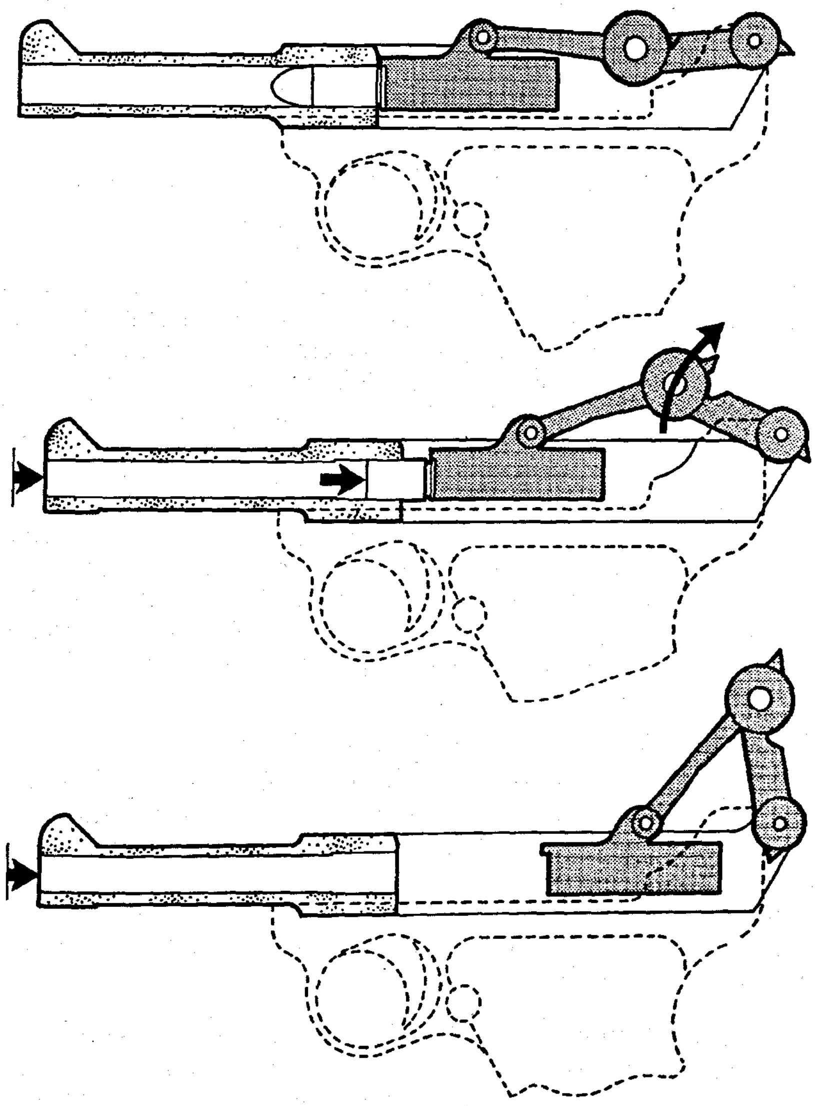


Fig 10.5 Toggle Joint Locking, Luger 9mm SL Pistol

The arrangements for mechanical safety before firing are illustrated in Fig. 10.6.

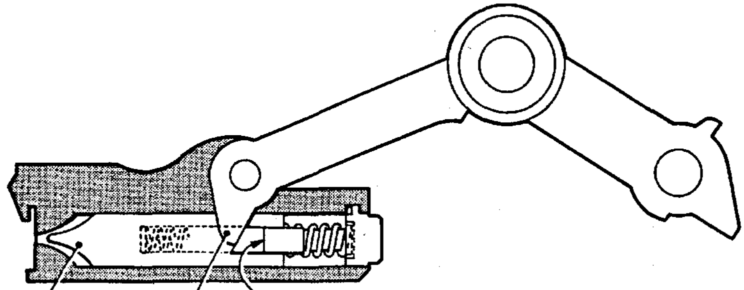


Fig 10.6 Luger Pistol, Cocking Action

As soon as the toggle joint is broken, the extension to the front arm hooks into the striker and withdraws it from the cap. The striker remains held back until the bolt goes forward; on the forward movement of the bolt the striker is held back by the sear, which is mounted on the left hand side of the body of the gun. If, through mechanical failure, the sear fails to hold the striker or releases it prematurely the hook on the toggle arm holds the striker away from the cap. When locking is completed and it is free to go forward there is not enough energy remaining to fire the cap and the diminished blow results in a misfire. This is a simple and reliable mechanism which is fully effective, provided that the weapon is used with the ammunition for which it was designed. Some 9mm ammunition is too powerful and, apart from damaging the extractor, places too great a stress on the toggle axis. The great advantage of this action, over others, is that the barrel recoils and runs out along its own axis with no tilting action.

The Rotating Bolt

The success of the principle of the rotating bolt lock used in manually operated breech loading rifles, led to its being applied to machine guns, automatic rifles and self-loading rifles. The principle can be well adapted to gas operated guns in which the gas piston carries a post. This rides in the hollow interior of the cylindrical bolt and causes the bolt to rotate by bearing on a curved cam path. It is shown in the case of the USA GPMG, the M60 (as illustrated in Fig. 10.7), and was taken from the German FG 42.

The piston post fits into the hollow interior of the bolt and bears against the curved cam path cut into the bolt. As the piston goes forward it tries to rotate the bolt but the shape of the body stamping prevents this until the bolt head with the locking lugs has entered the barrel extension. The bolt can now be rotated and the lugs move round in a cut away section of the barrel extension and lock the bolt to the barrel. The locking lugs are at the front of the bolt and give all the advantages of forward locking. Mechanical safety is obtained, before firing, because the striker is carried on the piston post which itself is unable to

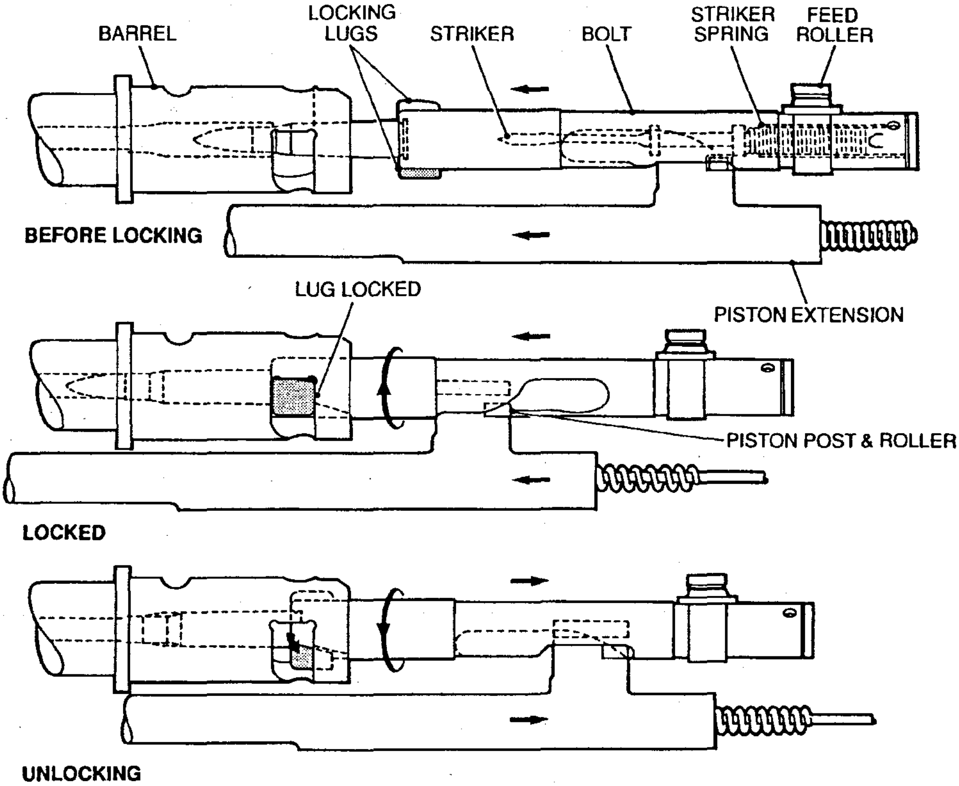


Fig 10.7 Rotating Bolt Application, USA GPMG M60

move forward along the cam groove until the bolt is rotated. The rotation cannot occur until locking is completed, so there is no possibility of premature cap strike. After firing there are two effects. Firstly, the position of the gas port ensures that the bullet is near to the muzzle before any gas passes through the piston wall. Secondly, the cam path has a preliminary section parallel to the bolt axis that ensures the initial movement of the piston post produces no rotation of the bolt. As a result the unlocking action does not start until the piston extension has moved back about 32mm. By this time the bullet is out of the barrel and the gas pressure is greatly reduced.

The Russian family of weapons consisting of the AK47 assault rifle, the Dragunov marksman's rifle, the RPK LMG and the PK series GPMGs, all have the same rotating bolt breech action illustrated in Fig. 10.8. This is carried into the newer AK-74 family.

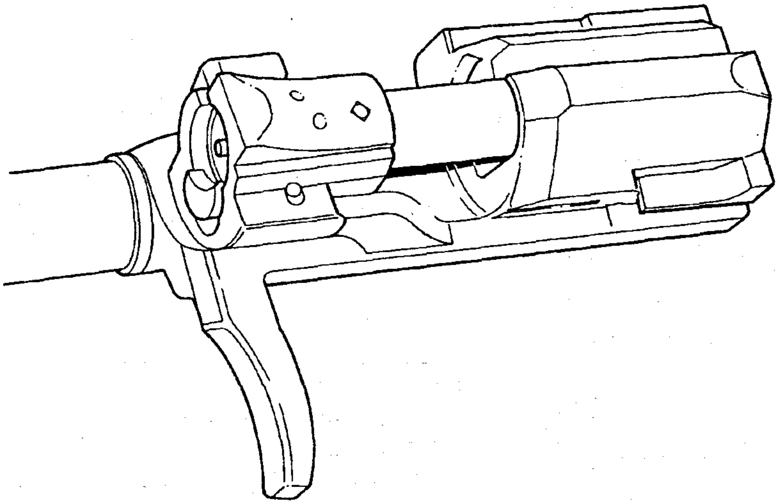


Fig 10.8 AK Assault Rifle Breech Assembly

The piston extension and bolt carrier are one machining. The bolt rides in the carrier. The carrier takes the bolt forward and the round is chambered. When the bolt can move forward no further, the piston extension has a further 33mm to travel and a curved cam path on the bolt carrier causes the bolt to rotate and lock to support the cartridge case. This is shown diagrammatically below at Fig. 10.9.

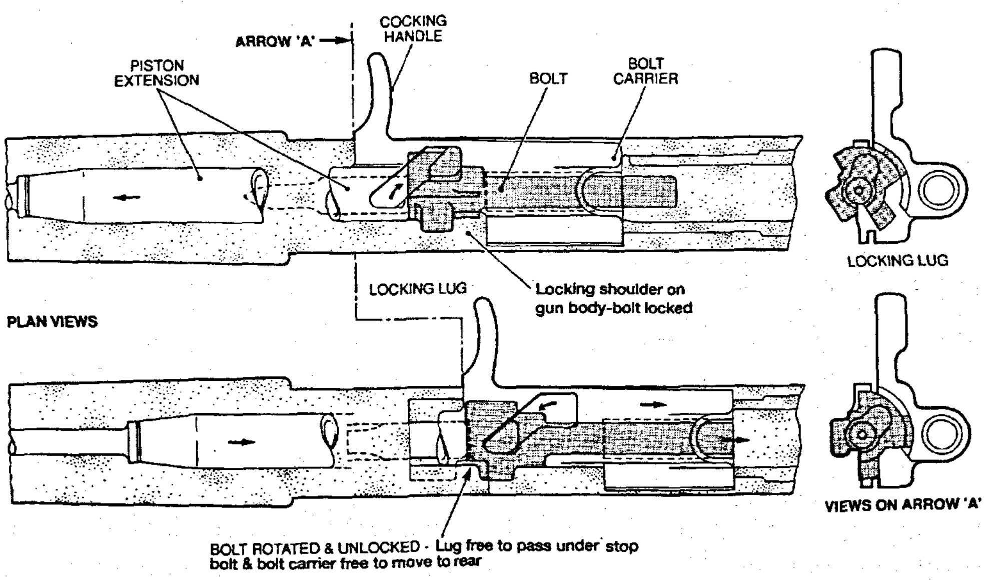


Fig 10.9 Rotating Bolt Kalashnikov AK47

The arrangements for mechanical safety are quite simple. Before firing, the bolt carrier must be fully forward to operate a safety sear, which must be depressed before the hammer can be released. The bolt carrier will have completed the bolt locking before it has moved far enough forwards to release the safety sear. After firing, the mechanical safety depends firstly on the gas port being well down the barrel, and that the bolt carrier moves back 6.4mm before the cam pin on the bolt is moved across the width of the operating cam slot and also that there is no bolt movement. When this free travel has been taken up the bolt starts to rotate and by this time the pressure is down to atmospheric. The principle of the rotating bolt is well established and it is possible to trace a continuous development from the American designed Lewis gun, through the German parachutists' rifle the FG42, to the modern USA Armalite rifle and the USA M60 GPMG. This type of locking device is probably the most widely used in the world.

The Rotating Nut Variation

The German LMG the MG17 employed the principle of the rotating bolt in a different fashion, shown in Fig. 10.10. The barrel extension was externally screw-threaded to take a substantial barrel nut. Into this barrel nut went the bolt, and interrupted threads on the bolt engaged inside the barrel nut. When the bolt went forward, rollers at the rear end engaged a curved cam path at the rear of the nut, causing the nut to rotate and so engaging the interrupted threads to lock the nut over the bolt. Thus the barrel extension, nut and bolt were all firmly held together with the bolt head supporting the base of the round in the chamber. After firing, the bolt recoiled pulling the nut and barrel backward. Mounted on the top and bottom of the nut were rollers that ran in cam paths in the body of the gun. After 6mm of free travel, these rollers engaged in their cam paths and caused the nut to be rotated rapidly. This unlocked the bolt; at the same time the cam path on the rear of the nut was engaged with the roller on the bolt and accelerated the bolt to the rear.

The barrel nut release catch is an essential feature of the design. Before it is depressed by the bolt it prevents movement by the nut which, otherwise, would not necessarily be lined up to allow bolt passage and the necessary clearance of the interrupted threads. Mechanical safety before firing is obtained by having a long firing pin going through the bolt. The firing pin is spring loaded and the spring is held back by a side lever which must be allowed to rotate out before the pin can move forward. Until the bolt is fully forward, and this means that locking has been completed, there is no aperture in the gun body to allow this arm to rotate to release the striker.

Mechanical safety after firing comes from the 6mm of free travel of the bolt, nut and barrel before the rollers on the barrel nut meet the curved paths in the body and unlocking starts. Whilst the bolt is recoiling this 6mm, the bullet has left the barrel and the pressure has dropped. The greatest objection to Rotating

Nut systems is that if the nut is omitted when assembling before use, the weapon can be fired with disastrous results! An essential requirement placed on the designer is to ensure that his weapon cannot be assembled incorrectly.

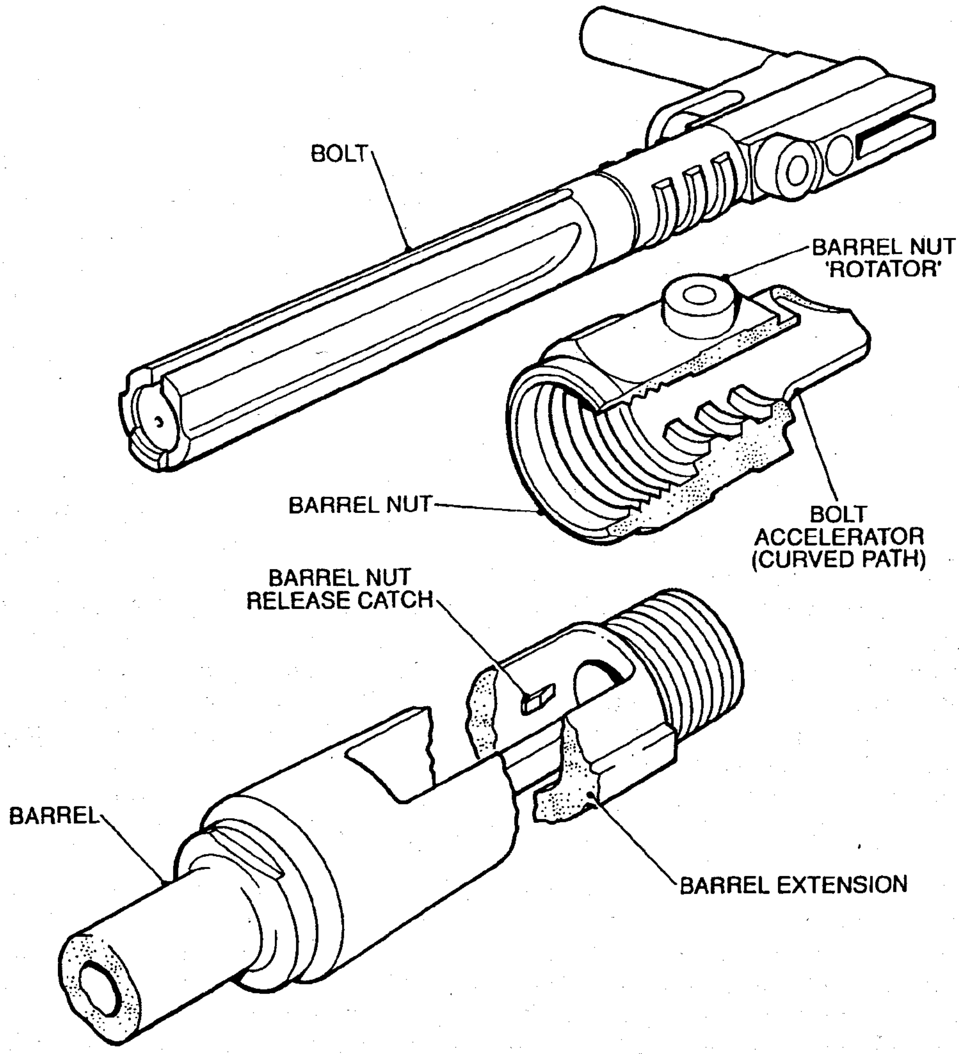


Fig 10.10 Rotating Nut Application, German MG17 LMG

The Tilting Block

There are several examples of the tilting block in current use. The best known of these of is probably the BREN L4 series, which originated in the Czech ZB design, used in the original .303in BREN and the 7.92mm BESA (Fig. 10.11).

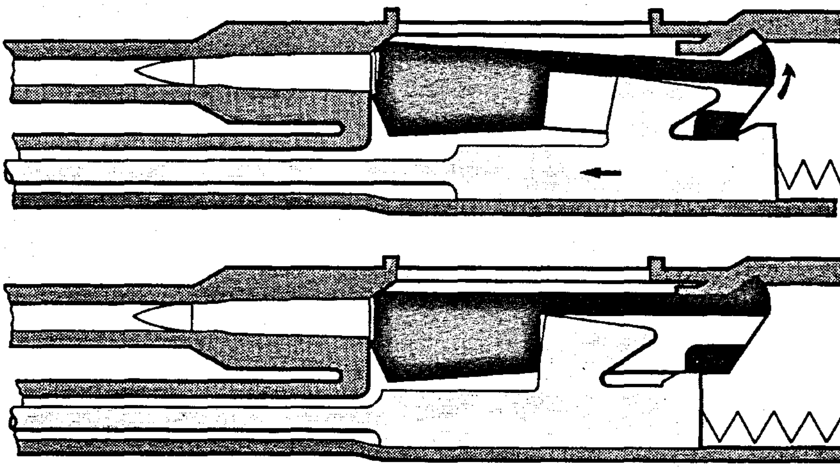


Fig 10.11 Tilting Block Application, BREN LMG

The breech block rides on the piston extension; locking is accomplished by a ramp at the rear of the piston extension which forces the rear of the breech block upwards. When the round is correctly chambered, the rear of the block is able to move into a recess in the top of the body. The piston goes further forward and the ramp rides under the block, holding it up into position in the locking recess in the body. Mechanical safety ~~before firing comes~~ from the non-alignment of the firing pin and ~~cap until locking~~ occurs. The free forward travel of the piston post after locking is completed before the front face of the piston post, acting as a hammer, contacts the firing pin. Mechanical safety after firing is provided by the position of the gas port and the free travel of the piston post before the inverted ramp pulls the block out of engagement with the body.

The same principle is applied to the L1A1 rifle which was derived from the FN FAL rifle, shown in Fig. 10.12. Here the forward movement of the carrier forces the rear of the block down in front of a locking shoulder in the body, and then the carrier overrides the bolt to hold it locked. After firing the piston forces the carrier back and the unlocking ramps strike the breech block bents and lift the locking bent out of engagement with the body. Mechanical safety before firing comes from the non-alignment and shrouding of the firing pin. Consequently the cap cannot be struck until locking is completed. Until the carrier is fully forward (i.e. locking is completed), the hammer cannot rotate since it is held up by a safety sear operated by the carrier.

The two previous examples have been of weapons in which the block has tilted in the vertical plane and both of them have been rear locking. The Czech Vz 52 SL rifle is an example where forward locking is employed. This is not quite so easy to achieve and can lead to extraction difficulties.

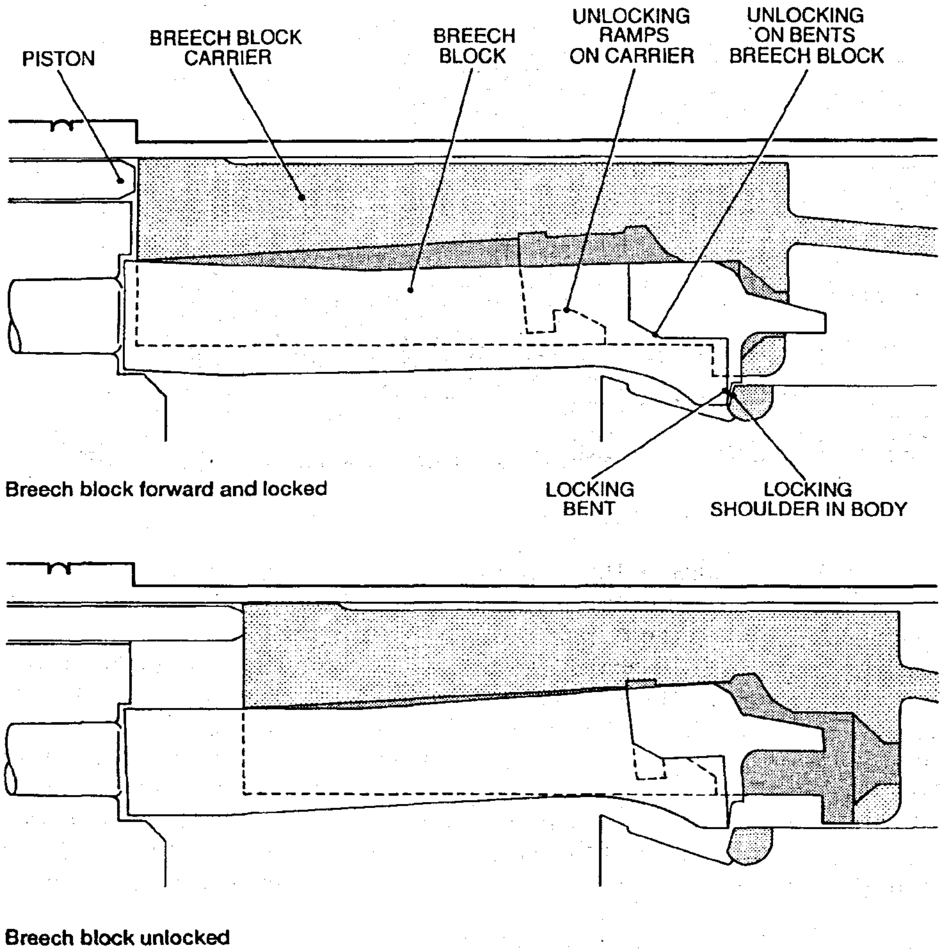


Fig 10.12 Tilting Block Application, UK, 7.62mm L1A1 SLR

The next example shown in Fig. 10.13 is taken from the Russian MMG the Goryunov M43, known also as the SG-43 and SGM. This is a gas operated MMG used both in the Infantry Battalion and in the battle tank as a coaxial machine gun. In this weapon the block tilts in the horizontal plane.

The top drawing shows the side view of the bolt mounted over the piston post. In the next two illustrations the method by which the block is tilted in the horizontal plane is shown.

Mechanical safety is achieved in this weapon using exactly the same principle as in the BREN, shown earlier, but with the block moving in the horizontal plane.

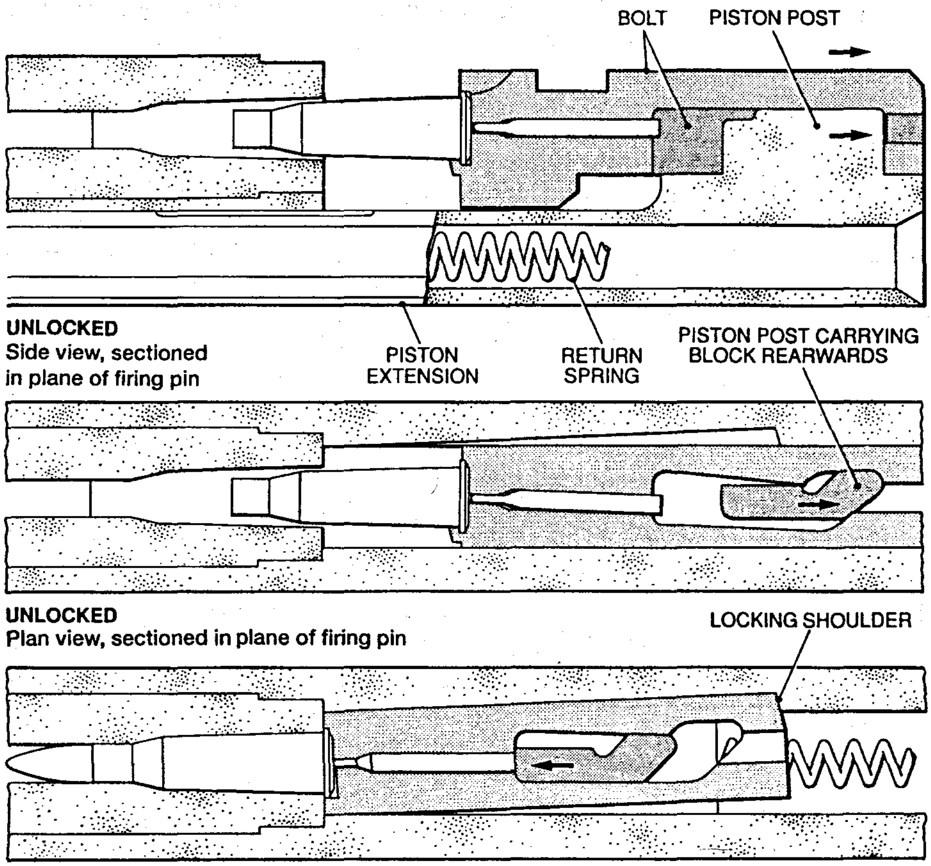


Fig 10.13 Tilting Block Application, Goryunov M43 MG

Sliding Breech Block

This method of supporting the base of the round has been common practice in guns for many years, but is not often met in automatic small arms. The earlier breech loading rifle frequently used variations on this system. The chief advantage of the system is that it shortens the body length of the gun because, instead of reciprocating, the block moves sideways. This reduces the body length from that required to accommodate the sum lengths of a complete round, the length of the bolt and the length of the compressed return spring. With a sliding block, the space required behind the breech face is that of a complete round plus a small clearance. This is particularly useful in a tank machine gun where space inside a turret is at a premium. There are, however, several disadvantages associated with a non ramming breech block where a separate rammer and extractor are required. Furthermore ejection of the fired

case is complicated. A recoil operated system is almost mandatory – otherwise there is no reciprocating member available to operate the feed mechanism.

These disadvantages outweigh the advantages so only a few designs have used this system.

Illustrated below (Fig. 10.14) is the USA tank machine gun, the 7.62mm M73, which was used in the M60 main battle tank. This is a short recoil gun. The breech block is very small and is located in a slide in the barrel extension. Under the barrel extension, a cam plate is fixed to the body and the cam curve is so shaped that the roller on the breech block following the curve is moved sideways across the barrel extension. When the barrel runs out the breech block is moved across to support the round in the chamber.

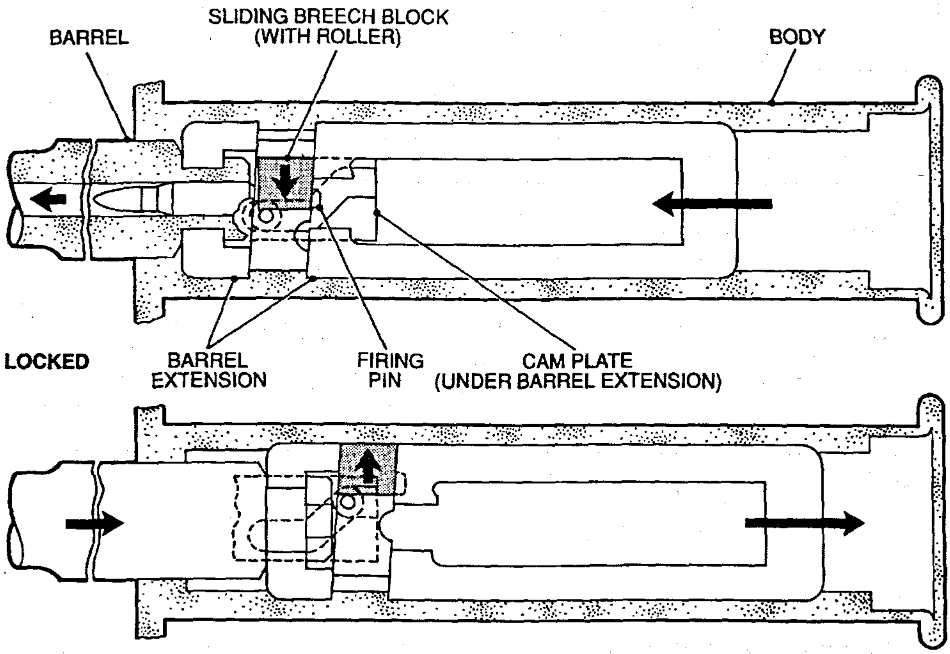


Fig 10.14 Sliding Breech Block Application, American 7.62mm Tank MG M73

The firing pin is contained within the breech block, so can only come into contact with the cap of the cartridge when the breech block is fully across and supported, giving mechanical safety. Mechanical safety after firing comes from the fact that the cam curve is straight for the first 0.5 in of travel; so the barrel must recoil this distance before the breech block starts to move across. By this time the bullet is well clear of the muzzle and pressure is safe. The extraction and feed problems have led to a complex system, described elsewhere in the relevant chapters. The latest US main battle tanks use a version of the 7.62 x 51mm FN MAG58, similar to the British L37.

Another breech mechanism similar in principle is that of the L21A1 RARDEN 30mm cannon. This is illustrated in the volume entitled *Cannons* in this series (see p. ii).

Projecting Lug Devices

The principle of the projecting lug is simply that some form of locking lug is forced out of the mass of the breech block to engage in a suitable recess in the barrel extension or body of the gun. The converse, where the lug moves from the body into the breech block, is also met. There are innumerable examples of this principle, varying chiefly in the nature and shape of the lug projecting outwards and the mechanism devised to force it in and out. It is preferable that there should be two lugs mounted diametrically opposite each other thus giving the bolt symmetrical support; but this is by no means essential, and the example below is that of the .30in Browning where a single lug is used to connect the bolt to the barrel extension (Fig. 10.15).

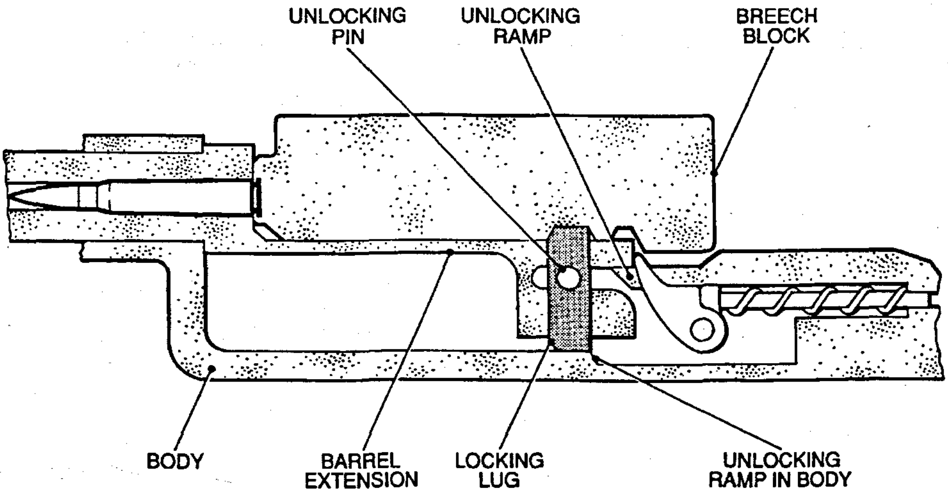


Fig 10.15 Lug Locking Device, Browning MG

The barrel extension carries a locking lug which is forced upwards by a ramp on the floor of the body as the barrel and breech block run out together. The breech block and barrel extension are thus firmly locked together before firing occurs. After firing, the breech block recoils, pulling the barrel with it. There is a pin standing out from the lug. This pin strikes the unlocking ramps that are in a frame attached to the body and do not recoil. The inclined planes on the unlocking ramp force the locking lug down out of the bolt, which is thus released from the barrel extension. Mechanical safety in this instance is secured before firing by so arranging the trigger mechanism that the trigger bar does not contact the sear until the breech block is far enough forward for locking to have been completed. After firing, the free travel of 6mm allows the

pressure to decline to a suitable low value before unlocking can start. The Russian gas operated MG, the RPD, uses a projecting lug system. This is a development of the earlier Degtyarov LMG used during World War II. The method used is shown at Fig. 10.16.

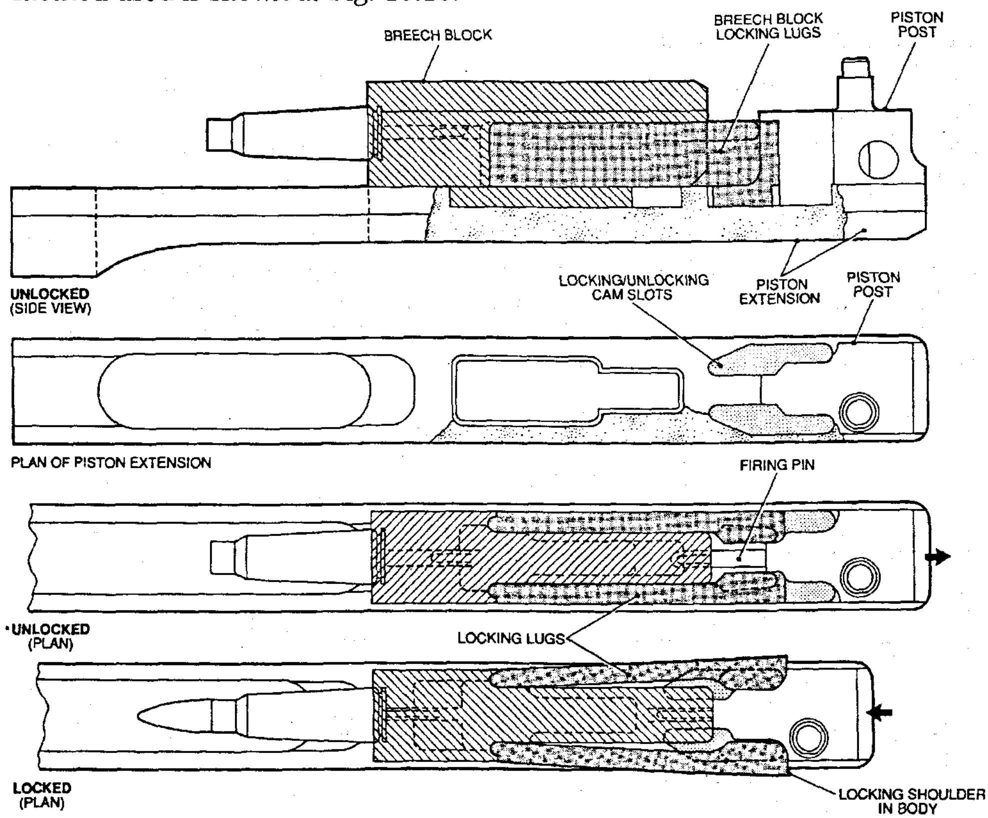


Fig 10.16 Locking Lugs, Russian RPD LMG

The top diagram shows the gas piston on which the breech block rests. The second drawing shows the cam slots cut around the piston post by which the locking lugs are forced in and out.

These locking lugs are pivoted on each side of the breech block and also extend rearwards on each side of the piston post. When the round is fully chambered by the bolt, the piston continues to move forward and the piston post forces the lugs to move outwards along the cam slots. The lugs then enter locking recesses in the body of the gun. When the round is fired, the two lugs act as struts connecting the bolt to the body and they are placed in compression whilst holding the bolt firmly against the chamber face. When the gas pressure in the cylinder drives the piston rearwards, the moving cam slots pull the lugs

inwards and the bolt is carried back on top of the piston extension. Mechanical safety before firing is provided by the piston post acting as a hammer to drive the firing pin into the cap. In order to strike the firing pin, the piston post must first force the locking lugs out into the body. Thus locking must be completed before the cap is struck. After firing there are the two parts to mechanical safety. The first is the position of the gas port and the second is the free travel afforded by the shape of the cam slots before the lugs are forced in. This Russian weapon provides a useful study in the design of a locking system. It is extremely easy to re-assemble the bolt after stripping and neglect to put the locking lugs in the bolt. When the round enters the chamber, the piston post will be in contact with the striker and the sudden arresting of the block could well cause the cap to ignite; with no locking pieces the effect would be disastrous. Again this reinforces the general point that it must be a feature of design to make it impossible to assemble the gun without the locking device, or any other part that affects safety missing or incorrectly assembled.

The German MG3 comes direct from the WW2 dual purpose machine gun, the MG42. This embodies a projecting lug system, based on rollers, which is shown at Fig. 10.17.

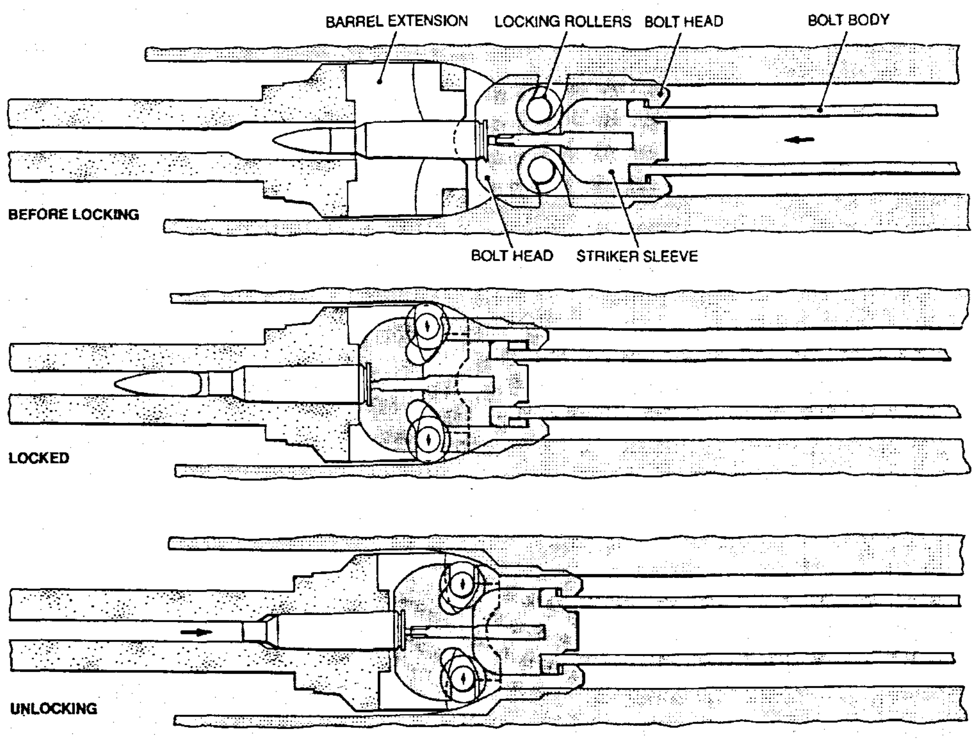
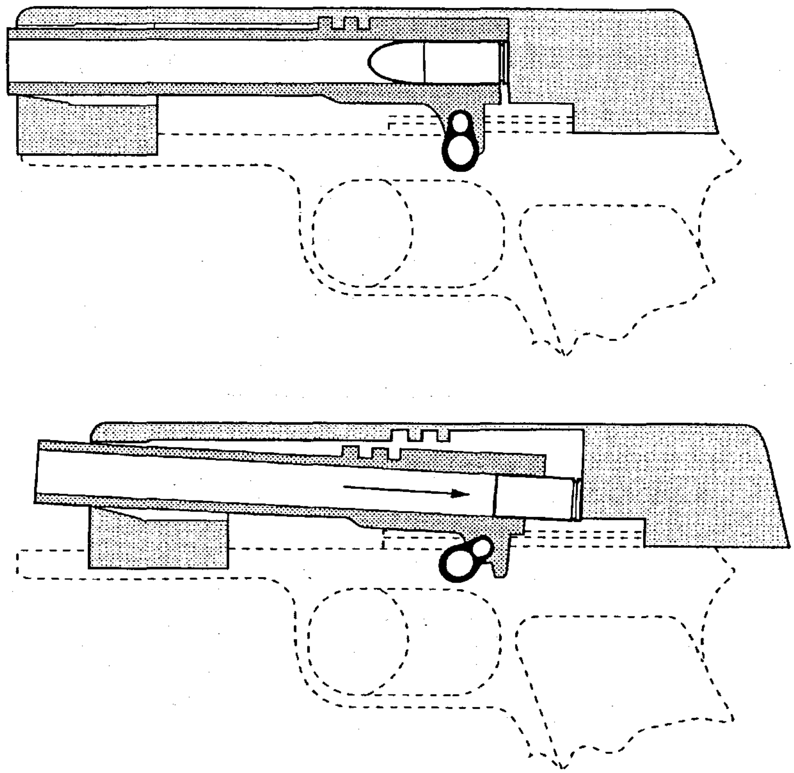


Fig 10.17 Lug Locking Device, German MG3 GPMG

The bolt is made in two parts, the head and the body. The bolt head has two undercut slots. The two roller locking lugs rest in these slots. The roller lugs are each shaped like the wheel on a wheelbarrow i.e. a shaft and roller in one piece. As the bolt comes forward on the loading stroke, the striker sleeve forces the rollers firmly forward into the undercut and they are held completely clear of the gun body. As the bolt head enters the barrel extension, the rollers enter cam slots in the barrel extension which drive the rollers back and out. The outward motion is greatly accelerated by the angled face of the striker sleeve which is being driven forward by the full force of the main spring. As the roller lugs have now moved out along the cam grooves in the bolt head and the cam grooves in the barrel extension, the bolt head and barrel extension are now firmly locked together. Mechanical safety in this form of locking is provided because the striker sleeve cannot come forward and thus allow the striker to hit the cap until such time as the roller lugs are forced fully outwards. This can only occur when the bolt head is in the barrel extension and is locked to it. The shaft of the roller holds the bolt head to the barrel extension during firing and also during 6mm of free recoil. Since the cam slots slope forwards, there is no force to unlock but, as an additional security measure, the striker sleeve continues to hold the rollers out. The large roller then contacts a cam path in the non-recoiling body of the weapon and the roller lug is forced inwards along the two cam paths to unlock the bolt head and at the same time accelerate it backwards. This acceleration is a requirement for all recoil operated rifle calibre weapons. It is achieved here by using the mechanical advantage obtained by the variation in angle in the cam grooves in the bolt head and barrel extension, which cause the bolt head to travel a longer path in the same time and therefore be accelerated relative to the barrel extension. Mechanical safety after firing comes from the 6mm of free recoil before unlocking commences. There is much to commend this design. Amongst other advantages, it precludes undue wear on the rollers which are able to present different bearing surfaces on each occasion.

The great majority of military pistols are designed to fire the same cartridge as the sub machine gun. This provides sufficient power to require a locked breech mechanism. Almost universally, the method of operation chosen is recoil. In the case of the Colt .45in Pistol, the lugs are projections from the barrel and the breech block is extended forward over the barrel to form the slide. There are recesses in the top surface of the slide in which the barrel lugs lock and the barrel is positively secured to the breech block which supports the case during firing (Fig. 10.18).

When the pistol is fired, the breech block is forced backwards and the barrel is pulled back with it. The link attached to the underside of the barrel is connected to the non-recoiling frame. As the barrel goes back the link pivots on the frame and pulls the barrel down. This disengages the locking lugs of the barrel from the recesses in the slide and the rearward motion of the barrel ceases whilst the breech block and slide continue rearwards. Mechanical safety



10.18 Lug Locking Device, .45in Colt SL Pistol

after firing is ensured by the length of time taken for the link to rotate sufficiently to free the barrel from the slide. When the slide returns, it pushes the barrel forward and the link lifts the breech end to enable the locking lugs to engage in the recesses in the slide. Mechanical safety before firing relies on the use of a disconnector. The disconnector lever rises into a recess cut in the underside of the slide when the slide is fully forward. As soon as the slide moves back it forces the disconnector downwards as the recess moves back. The movement of the bottom of the disconnector releases the sear which is rotated by its own spring to re-engage in the hammer bent. Only when the slide is fully forward can the sear be released. Should the sear, for some reason, jump out of the hammer bent, it will engage in the halfcock bent and hold the hammer clear of the firing pin. This mechanism is covered more fully in the chapter on trigger and firing mechanisms. It will be seen that the barrel rotates in an arc about the muzzle and that the slide continues to move back over the muzzle when barrel movement has ceased. This means that there must be a large dimensional tolerance between the muzzle and the collar of the slide and this can lead to inaccuracy.

The Browning 9mm HP Pistol below is very similar to the .45in Colt in principle, but employs a cammed path on the underside of the barrel, which recoils against a stud in the frame to disengage the locking lugs from the recesses in the slide as the barrel is lowered. All other characteristics are similar to the Colt (Fig. 10.19).

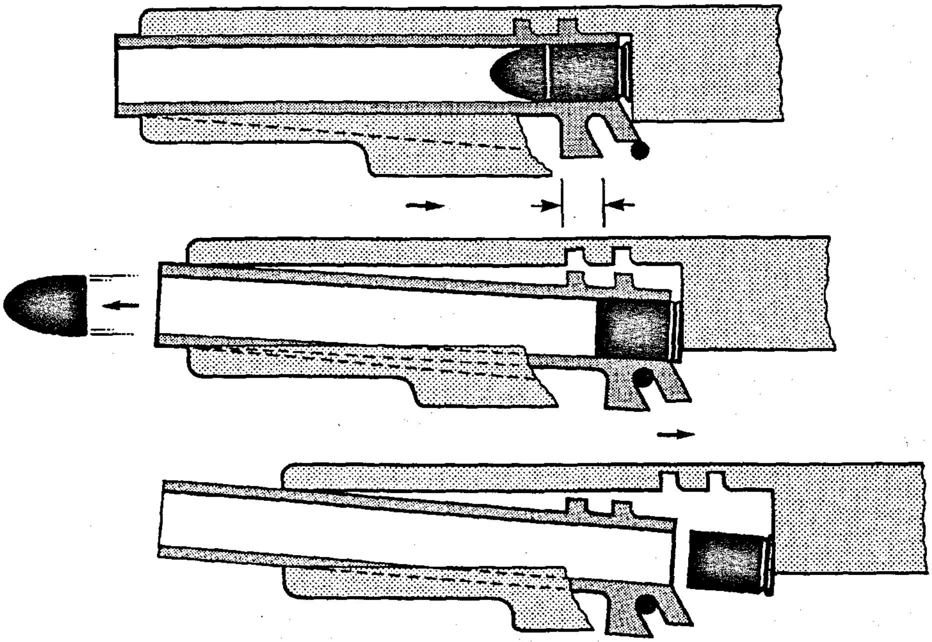


Fig 10.19 Lug Locking Device, 9mm HP Browning SL Pistol

The Walther P38 SL pistol came into service in the German army in WW2 and was taken up as the post-war weapon. It is a variation on the lug locking devices and, again, like the Luger, has the advantage of permitting the barrel to recoil along its own axis under control.

There are three main components as shown in Fig. 10.20: the barrel, the breech block slide and the frame. The barrel runs on slide ribs machined inside the breech block slide. The breech block slide moves on guide ribs in the frame. When the gun is ready to fire the locking lug is up, holding the barrel within the breech block slide. The locking lug is hinged to the underside of the barrel and is held up in the locked position by the frame of the gun. When the pistol is fired the breech block recoils pulling the barrel with it. After a short period of free recoil, an unlocking plunger strikes a face in the frame and the plunger is pushed forward. It contacts the locking lug and drives it down into a recess in the frame, thus separating the barrel and the slide and locking the barrel to the frame in the recoiled position. The breech block goes back driven by its own momentum with some blow back assistance.

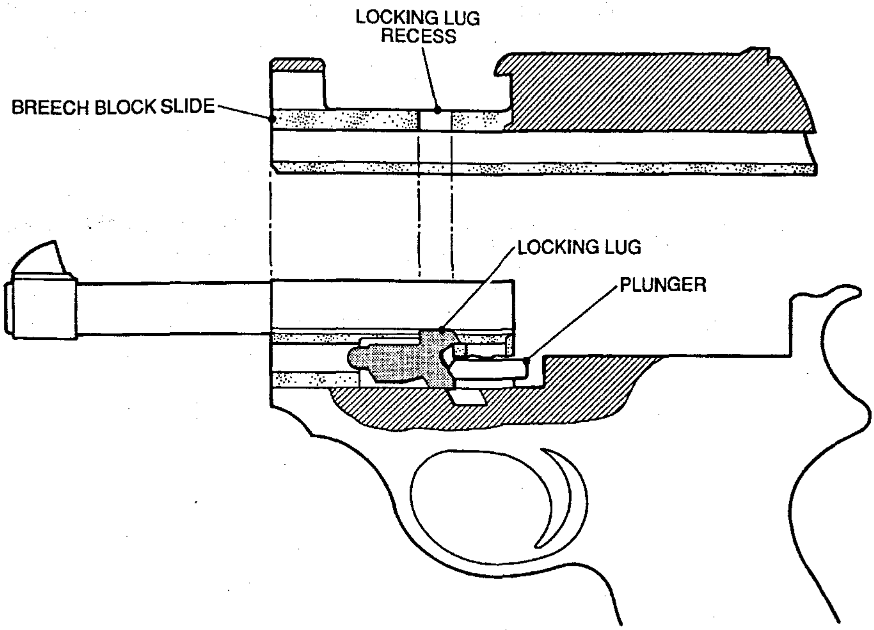


Fig 10.20 Lug Locking Device, P38 SL Pistol

The rib of the slideway holds the locking lug down into engagement with the frame. When the next round is chambered, recesses in the slide rib of the breech block slide once more come opposite the locking lug which is forced upwards, freeing the barrel from the frame and locking the barrel to the breech block slide. Mechanical safety, before firing, comes from the safety sear holding the hammer from rotating until the breech block slide is fully forward. Should it disengage, the firing pin is shrouded by the rear of the breech block slide. Mechanical safety, after firing, is produced by the free recoil of the breech block and barrel before the locking lug is depressed by the plunger. It is noteworthy that it is possible to assemble the pistol without the locking lug and to fire in this condition with disastrous results for both firer and weapon. This is a design defect.

Summary of Mechanical Safety in Automatic Weapons

The general method of producing mechanical safety is to ensure that:

- The striker is controlled by the device that provides support for the base of the cartridge in the chamber.

- The mechanism removing the support to the base of the fired round cannot operate until a certain pre-arranged time has elapsed to allow the pressure to drop.

- In blow back operated weapons relying on the inertia of the block and delay devices, the delay device actuates the striker and cannot do so until the breech block is closed and the round is supported.

- In recoil operated weapons there is inevitably a locking device which controls the striker and a period of delay before the bolt is unlocked.

- In gas operated long stroke weapons, the firing is controlled by the position of the piston extension which itself controls the locking arrangements. Where a short stroke piston is employed, the bolt controls the hammer via a safety sear and this arrangement applies also to direct gas action systems.

11.
Extraction and Ejection

Definitions

"Extraction" is the process by which the fired case or unfired round is withdrawn from the chamber.

"Ejection" is the process by which the extracted case or unfired round is removed from the feedway. Generally the case will be thrown clear of the weapon but the tactical employment or mounting of the weapon may demand that the case be retained in a suitable receptacle.

Extraction

The Problem

When the round is fired the radial pressure exerted by the expanding gases forces the case outwards against the chamber wall. When the pressure dies away, the case may or may not return to its original dimension. Ideally the case should not expand beyond its elastic limit. Sometimes the case has gone beyond the elastic limit and plastic flow has occurred. The general situation is best shown by the stress-strain curves in Fig 11.1.

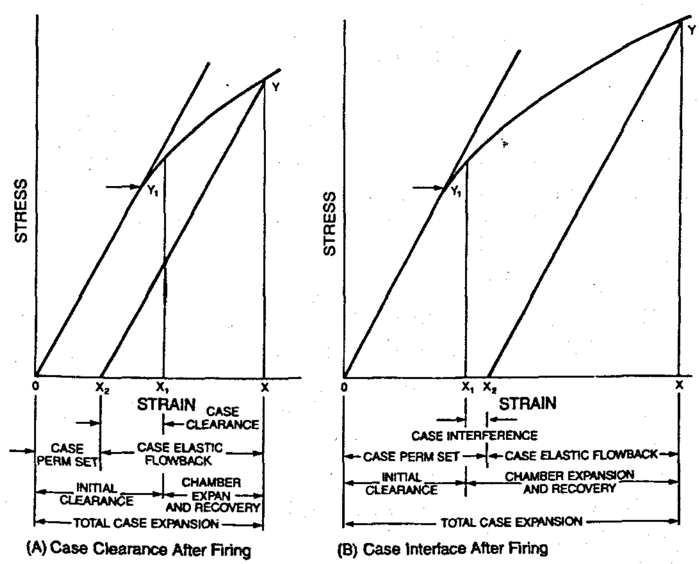


Fig 11.1 Case and Chamber Stress-Strain Curves.

The steel, of which the chamber is composed, will have a yield strength, dependent on the quality employed, but could well be taken as 600MPa. The quarter hard 70-30 brass used in many cartridge cases has a yield strength of about 300MPa. When the chamber is stressed by the gas pressure, it will dilate, and subsequently return to its original dimensions, because the stress will not exceed the elastic limit of the steel. The brass, which is of thin section, will follow the expansion of the steel chamber which will restrict its dilation.

In Fig 11.1 the total case expansion is represented by the strain OX. The stress producing this expansion is Y. For the case to enter the chamber there must be an initial clearance and this is represented by OX_1 on the figure. The chamber expands to X and, as the pressure falls off, returns to X_1. If the case is expanded beyond the elastic limit and beyond its yield strength, it will not return to O but to X_2 instead. This point is found by drawing a line through Y parallel to the slope of the elastic expansion OY_1. If OX_2 is less than the original clearance OX_1, a clearance $X_2 - X_1$ results leaving the case free in the chamber for extraction. (See case A). If OX_2 is greater than the initial clearance OX_1 the case will still be pressed hard against the chamber wall and this interference $X_1 - X_2$ (Case B) makes extraction very difficult.

It is for the designer to ensure that the yield strength of chamber and case, the pressures used, the chamber wall thickness, the temperature of the chamber wall and the initial clearance taken together allow a clearance between cartridge case and chamber wall when the pressure has dropped to the point when extraction occurs.

If this final clearance is not adequate, extraction difficulties occur.

Shape and Type of Cartridge Case

Two major factors affect the shape of the case. Firstly, the performance of the cartridge and, secondly, the type of operating mechanism to be employed in the weapon. The propellant load has to be contained in a cartridge case of suitable capacity; this may be achieved either by a long, small diameter case, or a large diameter case of shorter length. The design will have to compromise on the shape of the case, in order to satisfy both the requirements of the operating mechanism of the gun and the ammunition performance, as dictated by the role for which the weapon is required. There is also the need to keep the bolt movement and the body length as short as possible, which demands a short round. A fat, short round will require a larger magazine for a given number of rounds, but conversely the length must not be excessive. If a blow back mechanism is used, which will mean that the fired cartridge case is moving backwards out of the chamber whilst pressure still remains in the barrel, a parallel sided case is best used to ensure obturation during this movement and until the pressure has fallen to a safe limit.

In both gas and recoil operated weapons, the cartridge case normally shows some degree of taper. The reason is that, once the case has commenced to move, it no longer grips on the walls of the chamber, thereby ensuring rapid and smooth extraction. This initial movement of the case is known as 'Primary Extraction', and some form of additional leverage is generally found in weapon mechanisms to achieve this effect, as, for example, cam shaped locking lugs, which provide this extra force.

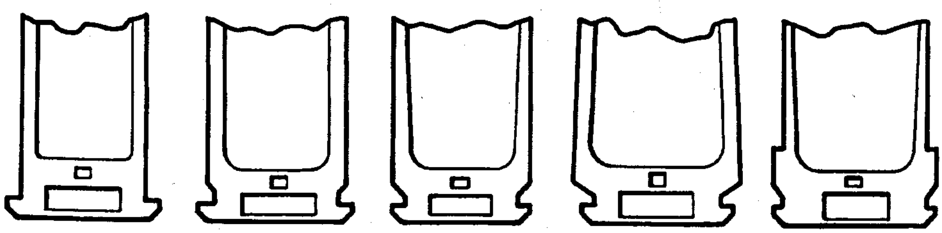


Fig 11.2 Ammunition Case Base Types.

The type of case may vary between rimmed, semi-rimmed, rimless, rebated and belted as shown in Fig 11.2. The case may be made of brass, steel, light alloy and even plastic or a combination. These factors will effect both extraction and ejection. The type of material, its hardness and cross-section will affect the obturation and the fit of the case in the chamber. It even may cause case failures on extraction, such as a separated case, or the extractor tearing through the rim without achieving extraction.

Lubrication gives a reasonable guarantee of easier extraction, but it collects grit and is therefore unacceptable in most service roles. The same effect can be achieved with a fluted chamber. Weapons with a very high rate of fire, such as the Aden and Mauser aircraft cannon, also use a fluted chamber to aid extraction. It is now thought that an air seal may be achieved momentarily during peak pressures with near parallel sided cases, thus ensuring the case is free when the pressure drops.

Effect of Operating Mechanisms on Extraction and Direction of Ejection

It has been shown that, for blow back operation, a parallel sided case is most frequently used, sometimes lubricated or with a fluted chamber. Normally the problem of extraction does not occur in this type of operation, since the empty case is the driving force, being blown back and extracting itself, but the mechanism will still require an extractor for misfires and training purposes with dummy rounds.

In gas and recoil operation the initial acceleration of the breech block, to which the extractor is normally attached, is often of a very high order. The loads that the extractor may be subjected to will be correspondingly heavy if the fired case shows any resistance to movement. Consequently the extractor must be robust, rigidly supported and controlled for the initial or primary extraction of the case.

Since extractors normally have to protrude beyond the face of the breech block, the rear end of the chamber must be recessed to accommodate them round the groove or rim of the case in the chamber. Too much clearance may leave the case unsupported, causing it to bulge or fail, resulting in malfunctioning of the weapon or faulty extraction.

The ejection of the empty case is a function of the mechanism, and the type of operation will affect this to some degree. Ejection is not difficult to achieve; in its simplest form a fixed protrusion from the body, working through a recess in the breech block, will cause the case to be ejected as the breech block brings the base of the case back against the protrusion. The problem with ejection is the direction in which to eject the case, or whether the case must be ejected into a receptacle or inserted back into its place in the conveyor (as in some strip systems). Generally, the problem hinges on the role for which the gun is required. If it is to be mounted in a tank or aircraft, the requirements will be different from those of a ground role. In the ground role, it is now generally considered desirable to eject the fired cases forward and away from the firer and his comrades, but other considerations do not always permit this. Modern GPMGs for example eject downwards. They do not then interfere with the operation of the gun, or injure members of the section. Sometimes deflector plates are fixed to weapons (eg, M16A2) to provide an additional assurance that the cases will not interfere with the firer, or go where they are not wanted, such as through vehicle hatches.

Primary Extraction

To provide the initial movement of the fired case during extraction, some additional leverage or mechanical advantage is generally provided in the mechanism. As has already been pointed out, this can be incorporated in the unlocking action, most simply by camming the locking lugs and/or the recesses. It is known as primary extraction. Primary extraction places additional strain on the extractor assembly, and therefore affects its design.

Extractors

An extractor is normally attached to the face of the breech block but may be operated by the action of the reciprocating parts. Its function is to engage behind the rim or groove of the cartridge case and pull it out of the chamber when the breech is opened. To achieve this it must be capable of springing over

the rim or into the groove as the round is loaded and must be positively supported during primary extraction so that it cannot jump out of engagement with the rim or groove.

There are five basic types of extractor:

- One piece claw.
- Multi piece claw.
- 'T' type.
- Combined extractor-ejector.
- Integral with breech face.

One Piece Claw Extractors

This type of extractor achieves two functions: it has sufficient spring to move over and into position behind the rim or groove of the cartridge case, and is so shaped and attached to the breech block that it will extract the fired case. This is the simplest form of extractor, being both extractor and extractor spring in one component and is shown in Fig 11.3. The heat treatment required to give this effect is difficult because two contradictory conditions have to be obtained, namely mechanical strength and spring action. Either a compromise has to be effected, or a different treatment is necessary to provide for each.

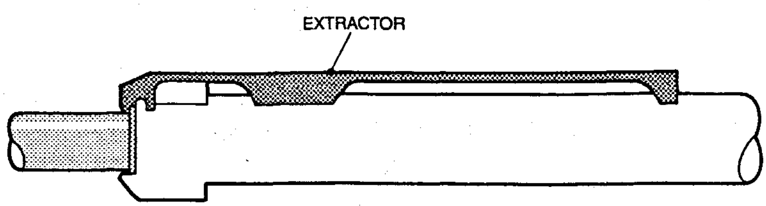


Fig 11.3 One Piece Claw Extractor, No. 3 Rifle

Multi Piece Claw

In the long run, it may be simpler to provide the claw and spring as two separate components, both from the point of view of ease of production and serviceability. The multi piece claw is a common method and is used in the case of the British BREN LMG and the 7.62mm L4 LMG and is shown in Fig 11.4. In the latter case an additional component, a stay, is provided to apply the spring pressure to the claw and also act as a spring guide. There are, of course, a multiplicity of variations in design, most of which employ either two, or even three or more, components.

The special feature of the BREN extractor design is the support of the claw during primary extraction by the stay, which is in turn supported by ramps on the piston extension, thus ensuring that the claw cannot jump the rim of the case during primary extraction.

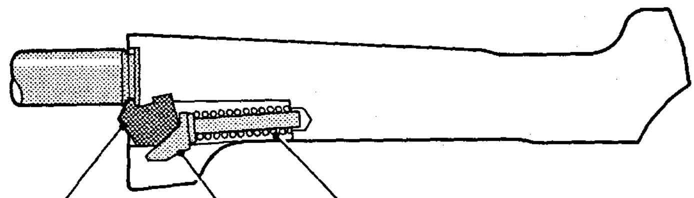


Fig 11.4 Multipiece Claw Extractor, 7.62mm L4 LMG

'T' Type Extractor

The 'T' type of extractor, as shown in Fig 11.5, is normally integral with the face of the breech block or bolt, being a 'T' shaped slot machined in the front face in a vertical plane. This slot may be designed for either rimmed or rimless cases. It was first used by Hiram B Maxim in his 1885 model MG. The extractor engages both sides of the case and cannot ride over the rim, but must move up or down at right angles to the axis of the case to engage it, thus dispensing with the need for an extractor spring.

This type of extractor may extract a fresh round from a belt feed, the extractor moving up, down, or sideways depending on the design of the gun, to convey the round into line with the chamber. It was used both on the Vickers and Browning MGs and is also used on the Hughes Chain Gun. 'T' slot or fixed extractors normally use the fresh round being fed onto the breech face to eject the spent case from the extractor. The PKM, and Browning MGs and the Mk 19 Automatic Grenade Launcher are among those weapons that use this method of ejection.

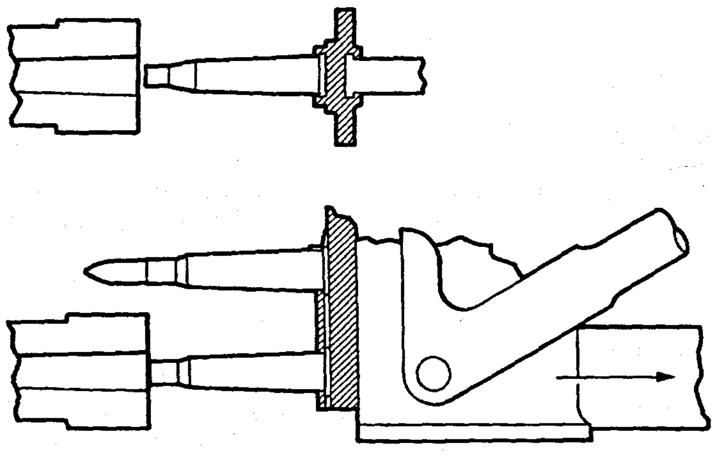


Fig 11.5 T-type Extractor, Vickers MG.

Combined Extractor/Ejector

The most common example of the combined extractor-ejector is found in the 'Break Down' action, ejector type shot-gun. It both extracts and ejects the empty case in one operation. To achieve this method it is required that the action of opening the breech will both clear the way for and operate the mechanism that ejects the empty case. The Martini Henry rifle employed such a mechanism, having a hinged block type of breech, similar in action to the Madsen MG. Revolvers are also equipped with extractor-ejectors which, are operated either by hand after the chamber has been swung clear of the breech plate, or, in the Enfield type, by the function of 'breaking' the pistol, as shown in Fig 11.6.

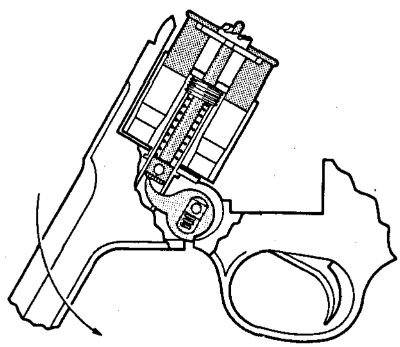


Fig 11.6 Combined Extractor-Ejector, Enfield Pistol.

Integral Extractors

Integral Extractors are really a variation of the 'T' type extractor. They are part of the breech block, but normally they only bear on one side of the case in the form of a lip, acting as both a guide for the round and a hinge for ejection. The Polsten HMG used this type, as shown in Fig 11.7, because the extractor needed neither to be very strong or spring loaded, since it was required to extract only dummy or mis-fired rounds. During normal operation the empty case operated the gun and drove the breech block, thereby extracting itself.

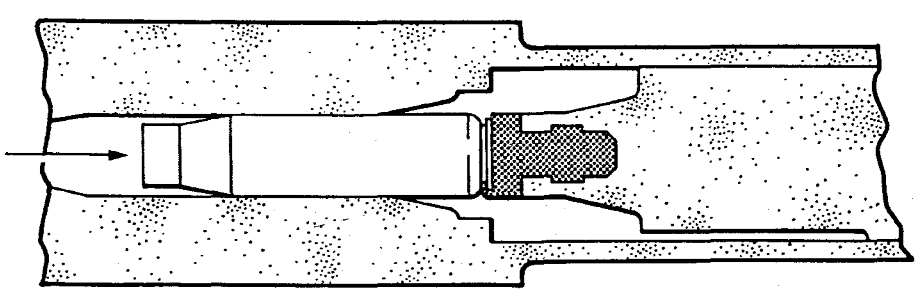


Fig 11.7 Integral Extractor Polsten HMG

Design Problems of Extractors

Strength, combined with compactness, is a contradictory requirement of an extractor mechanism. This sometimes breeds an inherent weakness in the design which cannot be overcome without complicating the gun mechanism. As a result, extractors and extractor springs are very often carried as spares, being a specific part of the gun store that is carried with it in action.

The extractor cannot cater for a cartridge case that fails during functioning, such as a separated case, where the forepart of the empty case remains in the chamber when the base is extracted. Normally a tool known as an 'extractor separated case', shown in Fig 11.8, is carried as a gun store to extract the forepart of the case. One end of the tool is usually identical to the base of a cartridge so that it can fit on the breech block face and be extracted by the extractor. The other end consists of a serrated, split diameter, capable of expanding against and gripping the inside wall of the forepart of the case, which has remained in the chamber.

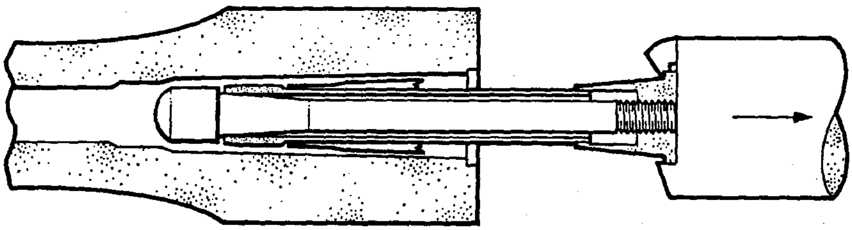


Fig 11.8 .303 Extractor Separated Case.

The rearward motion of the base of the tool wedges the serrated diameter against the portion of the case remaining in the chamber, causing the portion of the cartridge case to be gripped and then extracted by cocking the gun.

Ejection

Having acquired suitable extraction of the fired case from the chamber, plenty of energy remains available in both the empty case and the working parts to cause it to be ejected clear of the gun mechanism. The only real problem is where to, and in what direction, to eject the case, always remembering that it will be unpleasantly hot and cause fumes in a confined space.

For small arms used in ground roles, it has already been stated that the ideal is to eject the cases forward and away from the firer, safeguarding both him and the gun team under most circumstances. When machine guns are used in other roles, in tanks and aircraft, the problem is not so simple, but the ideal is to eject the case, via some medium such as a tube, away from the inside of the aircraft or armoured vehicle, or into a bag depending on the position of the gun.

Faultless ejection of the spent case is vital in order to clear the feedway for the next round. Mal-ejection will cause a serious stoppage. Where ejection necessitates the empty case being thrown or forced through a restricted space, the chances of faulty ejection are increased and this is so in some tank and aircraft guns. The best solution is to control the passage of the ejected empty case precisely, thus reducing the chance of it jamming. This method has been applied both in tank and aircraft machine guns. The British Vickers MG and the L94 Chain Gun are examples, where it is required to eject the empty case clear of the gun compartment. An alternative is to replace the fired case in its feed conveyor as in the Italian Breda Mod 37 Tank MG, which replaced the empty case in its strip feed. It is also essential to ensure that the empty case cannot come into contact with the mounting or, as happened initially with the British L7A1 GPMG, into contact with part of the tripod, from which it rebounded into the gun to cause a stoppage.

Basic Types of Ejection

There are five systems commonly met within small arms:

- Fixed or pivoted in bolt way.
- Rocking type.
- Push rod type.
- The combined extractor-ejector.
- Two stage ejector.

Ejector, Fixed or Pivoted in Bolt Way

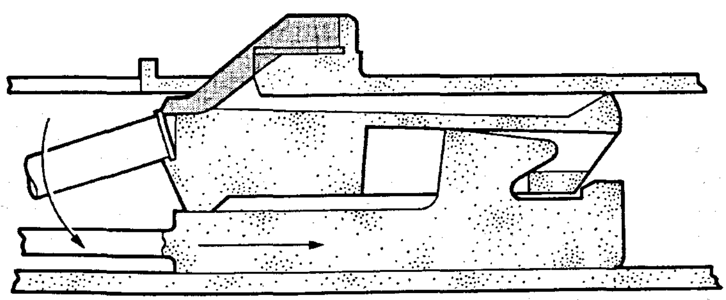


Fig 11.9 Fixed Ejector, BREN LMG

For the BREN gun, the ejector is fixed to the body of the gun and operates through an ejector clearance way on the top or side surface of the breech block, as shown in Fig 11.9. As the breech block retracts, extracting the empty case with it, it carries the base of the fired case up against the prong of the ejector. This ejector rotates the case about the extractor. Continued rearward movement of the breech block flicks the cartridge case out through the gun ejection opening.

In some guns, this type of ejector is pivoted at the point where it is attached to the gun body, so that it may move upwards or sideways out of the path of the breech block. This device dispenses with the need for a long clearance way in the breech block for the ejector prong to move through as the breech block operates. Other types of this ejector are buffered, this ensures smoother ejection and reduces the chance of mal-ejection due to distortion of the empty case causing jamming in the extractor. The fixed boltway ejector is the simplest form of ejector there is. It is employed on many weapons of many nations. The Russian Guryunov M43 employs a conventional type ejector whereas the French General Purpose machine gun, the AA52, utilizes the under side of the feed tray to force the case down and out of the bottom of the gun.

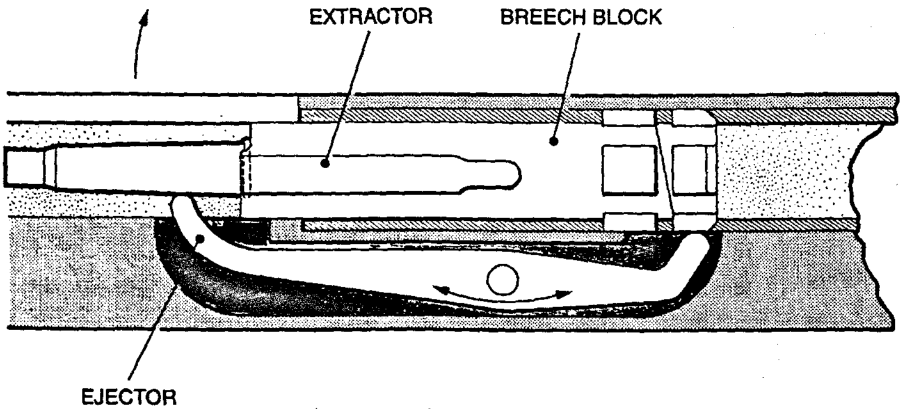


Fig 11.10 Ejector, Rocking Arm Type, .303in Lewis Gun

Rocking Type Ejector

This type of ejector may be either mounted pivoted to the body and operated by the reciprocating movement of the breech block, as shown in Fig 11.10 for the Lewis gun, or it can be pivoted to the breech block and operated by a ramp on the body in the passage of the breech block. An example of this, taken from the Swiss rifle the SIG 510-4, is shown in Fig 11.11. A rocking type ejector strikes the side of the case, as opposed to the fixed type extractor which strikes the base of the case. The rocking type is not therefore so positive, but is less violent in operation due to the elasticity of the wall of the cartridge case.

Push Rod Type Ejectors

In principle, this type of ejector achieves the same effect as the fixed type in as much as it operates through the face of the breech block. The ejector rod passes through the breech block to bear on the case of the cartridge case clear of the cap, and is usually operated to strike the case on the edge opposite to the extractor.

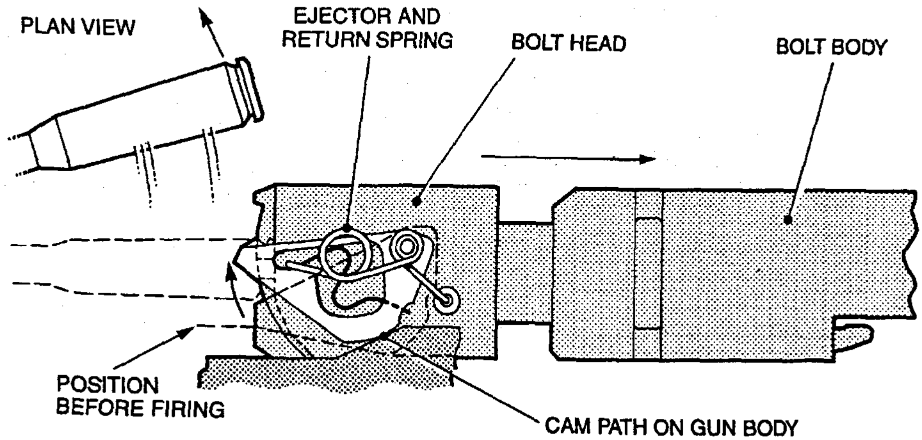


Fig 11.11 Ejector Cam Operated Type, 7.62mm Swiss SIG 510-4

The action of the ejector may be applied in different ways, either by a straight mechanical push caused when the rear end of the rod comes up against the body of the gun, as the breech block reaches its rearward limit, or by a spring or a buffering action. In most cases the rod is buffered to prevent the action of the ejector rod being unduly severe, which might cause mal-ejection or breakage of the extractor.

The German MG3 GPMG, employs a combination of a buffered, push rod type of ejector and is shown in Fig 11.12. It consists of three parts: the ejector which protrudes through the face of the breech block, the operating push rod which runs through the body of the breech block and the operating collar at the rear of the breech block which contacts the buffer in the rear face of the gun body. The operating collar operates the ejector as the breech block reaches its rearward limit of travel.

This type of ejector is positive, simple in operation, and prevents the necessity for a cut away groove in the breech block, enabling the top surface of the breech block to be used for other purposes, such as operating the feed mechanism, which is the usual case in modern GPMG.

The British L7A2 GPMG employs a spring operated, push rod type of ejector as shown in Fig 11.13. As soon as a round is loaded, it forces the rod or plunger ejector back into the breech block, putting a spring in compression. When the empty case is extracted from the chamber, the spring reasserts itself, ejecting the case downwards out of the gun over the extractor.

Some small rifles and small calibre pistols use the striker as a spring operated, push rod ejector. This type is only suitable for low power, rimfire, cartridges.

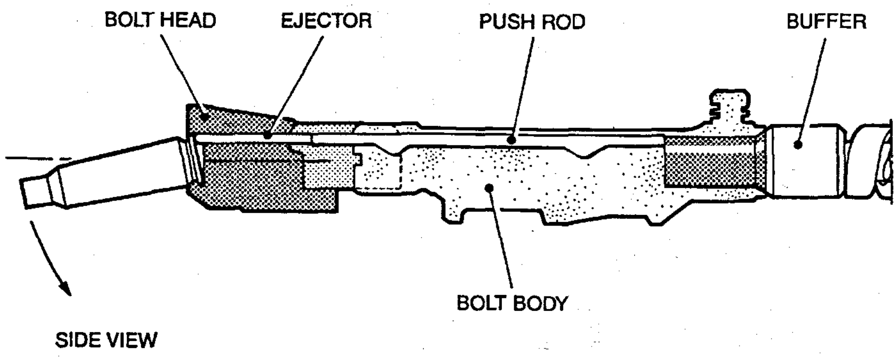


Fig 11.12 Ejector, Push Rod Type, 7.62mm MG3

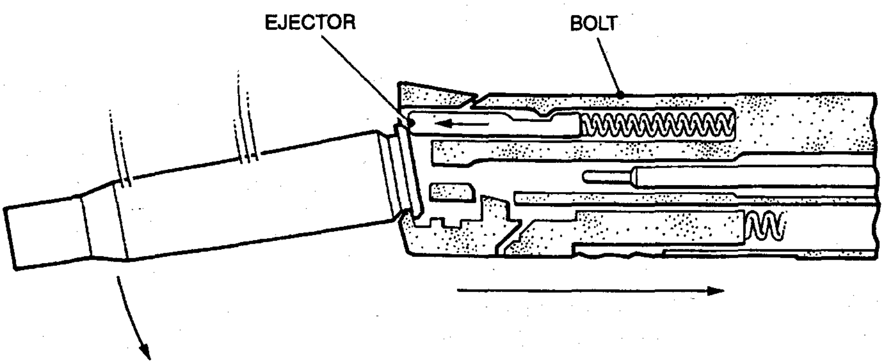


Fig 11.13 Ejector, Spring Loaded Rod Type, 7.62mm L7A2, GPMG

Combination Extractor-Ejector

In this system the extractor is normally a portion of the rear face of the chamber, which is able to move in relation to the chamber. This portion of the chamber or extractor can be operated either by hand when the breech is open, or automatically by the action of opening the breech. Provided it is used in conjunction with rim type ammunition, the rearward movement of the extractor will both extract the fired case and flip it clear of the mechanism of the weapon. This type of extractor-ejector is commonly found in both ejector type breakdown shot guns and revolvers. In the case of the shot gun, the action of opening the breech operates the ejector by triggering a spring under compression as shown in Fig 11.14. On the Enfield type service revolver, the action of 'breaking' the weapon achieves the same effect. Solid frame pattern revolvers have 'swing out' cylinders for loading and unloading; in their case the combined extractor-ejector is operated by hand.

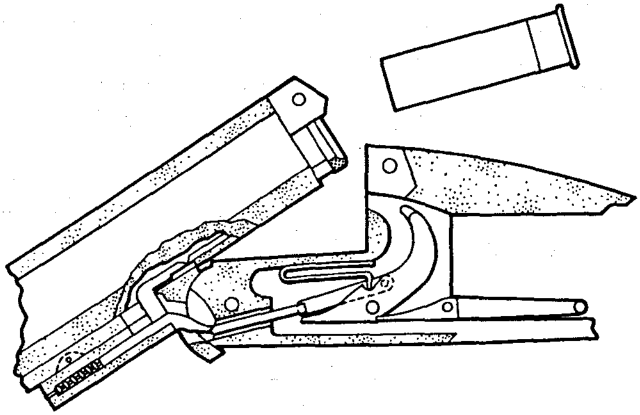


Fig 11.14 Combined Extractor-Ejector Shotgun.

Two Stage Ejectors

This type of ejector achieves two objects: firstly it ejects or displaces the fired case from the face of the breech block and, secondly, it ejects the case clear of the gun compartment, through some medium such as a tube. This is a requirement for both vehicles, armour and aircraft installations. Mechanically, these objectives are achieved by ejecting the fired case in the normal way on the unloading stroke of the breech block, then arresting and retaining the fired case in another portion of the mechanism which both positively holds and positions it. As the breech block travels forward again on its loading stroke, a protrusion on the piston strikes the base of the fired case, which has been held in its path, driving it forward down a tube which guides it clear and outside of the gun compartment. The L94 Chain Gun is an example of this method, the ejection tube being contained in the barrel shroud.

The extraction process in the RARDEN 30mm gun is of this type and is shown in Fig 11.15. The gun operates on the long recoil principle. The breech block opens after 230mm of recoil. As it opens it draws the rammer body down until the rammer claw assumes the vertical position and grips the empty case.

The barrel runs out and the empty case is left in the rammer claw in the rear. When the rammer arm has been rotated to the top position, the feed slide pushes a live round into the rammer from the right and this action pushes the empty case onto the ejector way on the left hand side of the gun. The case remains in the ejector way until the next round has been fired. After recoil the breech moves forward and the ejector collects and ejects the empty case. Thus as the gun runs out, one empty case is ejected and another one placed in the ejector way. The advantage of this system is that the case is ejected forward out of the vehicle and does not impede the gunner in his duties, nor does the case bring any toxic fumes with it into the crew compartment.

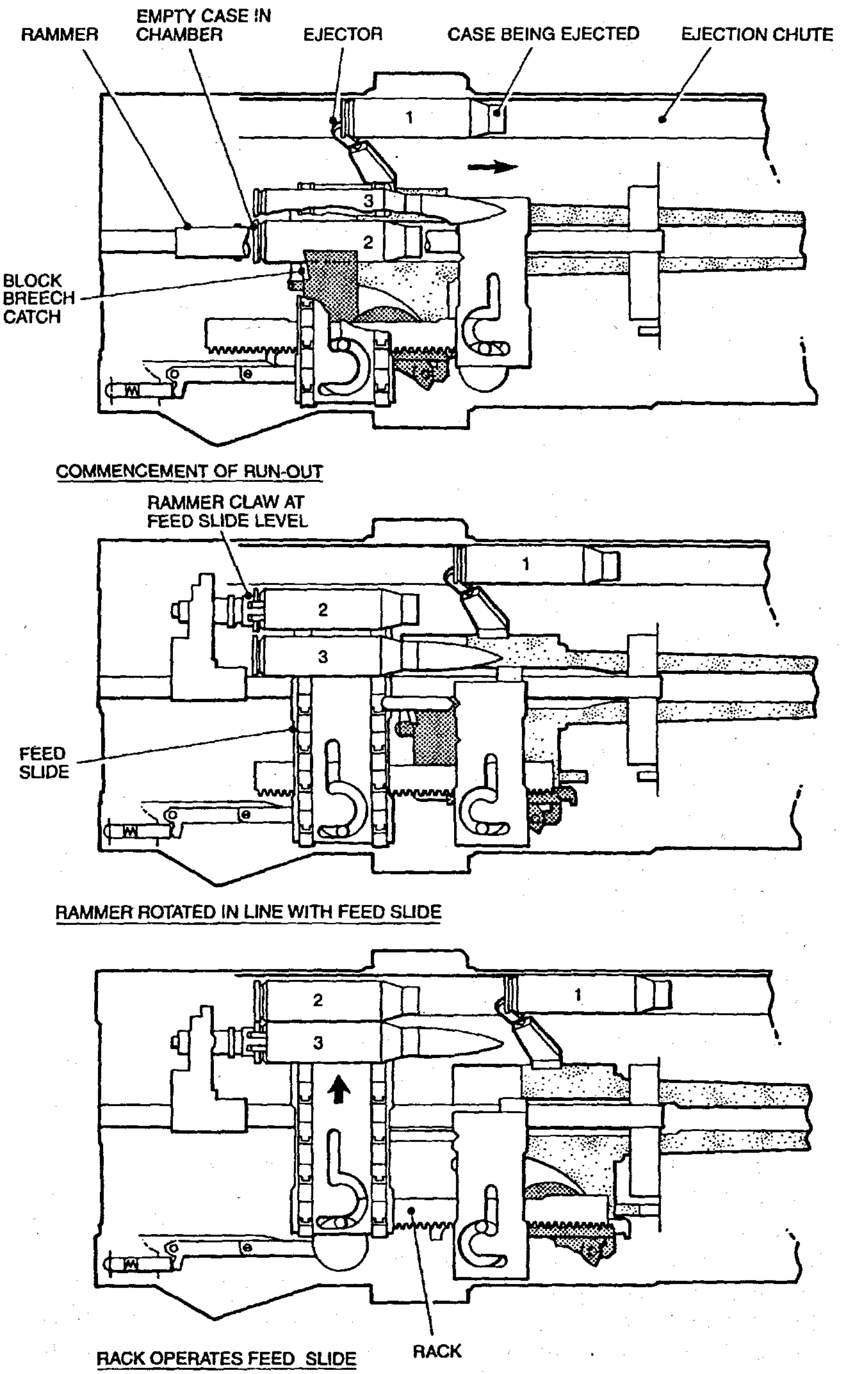


Fig 11.15 Two Stage Ejection, RARDEN 30mm Cannon.

Special Ejector Features

To assist in the prevention of 'caps out' in automatic firing weapons, the ejector sometimes incorporates a feature for ensuring that the cap is retained in the fired case. The BREN LMG has this feature in its ejection system: the ejector is designed to strike the base of the cartridge case immediately outside the cap chamber with a chiselling effect. This blow will burr the brass over the periphery of the cap, preventing it from coming out should it be loose. Downward ejection has the advantage of allowing displaced caps to fall out of the gun, provided they do not cause a jam first. Caps will not come out of good quality ammunition in ordinary guns, but the high acceleration imparted to the cases during ejection from guns with cyclic rates over 1,000 rpm occasionally causes caps to fall out.

Design Problems of Ejection

Since the working parts of a weapon will be moving at a high velocity during ejection, one of the problems of ejection is to so design the ejector that its operation is sufficiently moderated in relation to the forces to prevent both gun component breakages and mal-ejection of the case. For this purpose direct acting ejectors, on guns with a high cyclic rate of fire are buffered, as for example the German MG3 ejector. Finally, like the extractor, the ejector, although only a small part of a gun mechanism, must be fully reliable and serviceable, since any failure will cause a bad stoppage in the gun mechanism.

12. Feed Systems

Definition

The term 'Feed System' covers three main functions, all of which may vary; they are:

- The device which holds the ammunition to the gun and conveys the ammunition to the feed mechanism.
- The feed mechanism, which positions the round ready for loading and may include operating the conveyor which carries the round.
- The function of loading the round into the chamber.

Since the last two of these functions depend entirely on the first, which in turn depends on the role for which the gun is required, consideration will initially be given to the different types of conveyors and magazines which form the basis of the feed system.

Feed Systems

Types

The original machine guns, such as the Nordenfeldt, had a hopper type feed system, which was attached over the breech of the gun and into which the rounds were placed. It relied on gravity to position a round ready for loading. The improvement in machine guns and the expansion of the role for which they were required made this method unsatisfactory. It should be noted here that in the machine gun more stoppages are caused by faults in feed systems and mechanisms than by any other mechanical deficiency.

There are two basic systems for supplying a modern gun with cartridges:

- Magazine.
- Belt.

These systems may be further sub-divided into:

- Magazine: box, drum, gun driven or spring driven, and tubular.

- Belt: Fabric, stripless or metal strips, all metal or with fabric, metal disintegrating link belt, flat or articulated strip

Effect of Different Weapon Roles

Different types of feed systems have major fundamental differences, in particular with regard to:

- Method of attachment to the weapon.
- Number of rounds immediately available in any one system.
- Method of carriage and supply.
- Serviceability.

It is therefore necessary to get quite clear how the role of the weapon must, to a certain extent, dictate the system of feed.

Method of Attachment

In all these basic systems of feed, the method of attachment and the replacement of the empty system by a filled one on the gun, is of paramount importance. In action it must be done as quickly as possible. It is generally easier to achieve this rapid replenishment of feed with a magazine rather than with a belt. With the latter either the feed mechanism has to be operated manually, or a feed cover lifted before a fresh belt can be positioned in the mechanism. For the closer range roles in which light machine guns or submachine guns are required, magazines are used in preference to the belt. They only require to be clipped into position on the magazine opening and the first round is immediately in the loading position. Furthermore, a feed system stoppage may be rapidly remedied by the replacement of the magazine.

Obviously a magazine restricts the amount of ammunition immediately available for continuous or sustained firing. Where the role of a ground machine gun is general purpose (for both light or medium machine gun roles) a feed cover may be designed to accept either belt or magazine feed systems as required. While a number of recent LMGs (Minimi and Negev) have such dual feed systems, none have been fully satisfactory.

Although a magazine may provide the most rapid form of replenishment of the supply of ammunition, both the total number of rounds required to be immediately available and the efficiency of the system for a particular role will affect the final solution.

Number of Rounds

The number of rounds immediately required is dependent upon the role for which the weapon is required. The more rounds available which can be satisfactorily transported within the organisation of any particular sub-unit will reduce the number of replenishments required of the system in action. To take this point to an extreme; it may eliminate the necessity of a replenishment at all and thus dispense with that particular problem. If a section LMG were belt fed by a serviceable and portable system, the ammunition load could be split between the other section members. Lengths of loaded belts would need only be hooked to the belt already in the gun feed, thus achieving the dispersion of the ammunition load in a portable manner and yet dispensing with the need for changing the feed system. However, the desirability at close quarters of being able to remedy a feed stoppage by the simple exchange of a magazine is a factor not to be overlooked.

Method of Carriage

The method of carriage and breakdown of ammunition loads may be of particular importance in the case of infantry. It is desirable to be able to subdivide the load into both small and serviceable components. It might be argued, that, for the infantry section, a loaded magazine for the LMG would be better than loaded lengths of belt. Nevertheless, it should not be overlooked that some advantages can be achieved if a suitable belt system, capable of being broken down, could be developed and this is one of the advantages of the disintegrating link system of belt.

Serviceability

Serviceability is perhaps the most important factor of all, bearing in mind the adverse conditions to which a particular type of feed system might be subjected in certain roles. Taking again the infantry section as an example, it may be argued that a magazine type system may best stand the rigours to which service conditions will subject it and still function satisfactorily. It is compact, robust, can be made waterproof and is comparatively impervious to sand, mud and dirt. However, lengths of belt are similarly serviceable if packed in suitable containers. The solution is probably a compromise, the ammunition being carried by the section members in factory packed, water- and dirtproof packages, suitable for immediate insertion into a fixed type magazine holder on the LMG.

Taking all these factors into account, consideration will now be given to different types of feed systems for supplying a modern machine gun.

Box Type Magazines

Box magazines are made in various forms and may have curved or straight

sides. They consist of three essential parts, as shown in Fig 12.1:

- Casing.
- Spring.
- Platform or follower.

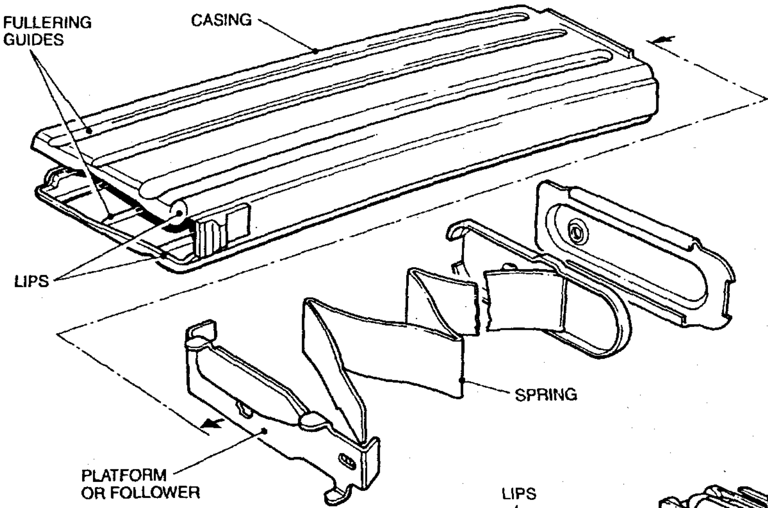


Fig 12.1a Box Type Magazine for 7.62mm L4A1 LMG

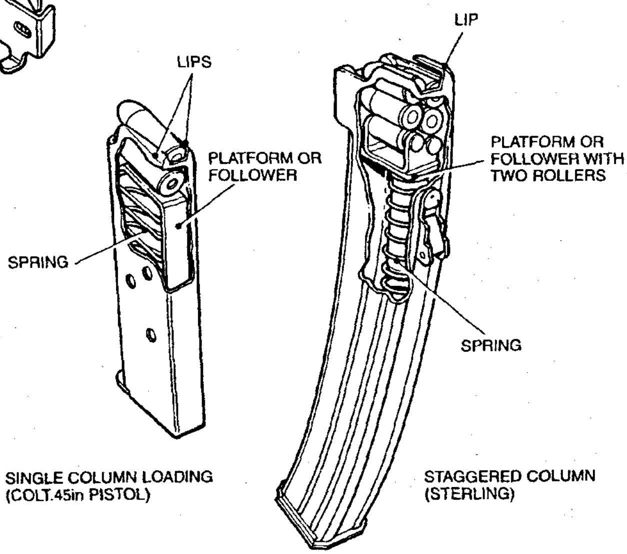


Fig 12.1b Arrangement of Rounds in Magazine for, Colt .45in & L2A3 SMG

In all types of box magazines the rounds are loaded in column, either single or staggered. The latter loading allowing more rounds in a given length of magazine. The size and capacity of the magazine is limited by the handiness of the resultant loaded weapon, the weight of the ammunition and the role for which the weapon is required.

Design Problems

In all magazines certain design features are essential to ensure the correct functioning of the feed system, and in turn, the efficiency of the gun. The main points of design in the magazine are:

- Control of the displacement of the rounds in staggered columns.
- Fullering guides for reduced friction, clearance space and control.
- Lips of the Magazine.
- Platform spring.
- Magazine attachment devices.

A good magazine design can be difficult to achieve but can make all the difference in the successful functioning of a weapon. The best weapon is useless if the feed mechanism is useless.

Control of Cartridge Displacement

In a staggered column type of magazine, control of cartridge displacement is critical, in order to ensure that the thrust of the magazine spring forces each succeeding round out into the magazine lips without causing the rounds to jam by interlocking the two columns.

The overall successful working of the magazine is affected by the following factors:

- The shape of the magazine follower.
- The width of the magazine in relation to the size of the round and the degree of fullering.
- The form of the lips.

Fullering

The fullering in the magazine is the indented ribs pressed into the wall of the magazine to give stiffness and to act as guide or rails for the column of rounds in the magazine. It also provides control of the column with the minimum of friction to the sides of the rounds, and allows for a large clearance space for any ingress of dirt, mud, and sand which would otherwise jam between the side of the magazine and the rounds, causing malfunctioning.

Magazine Lips

The lips of the magazine position the round ready for the breech block or bolt to ram it into the chamber. A round is long in relation to its diameter and is slightly displaced from the axis of the bore at the moment it commences to load. The angle at which it is held must be accurately controlled if the cartridge is to be forced into the chamber without causing a jam. Because of this the lips must be accurately made and strong enough not to be easily damaged or their form changed by service use. A solution to this design problem is to have the lips of the magazine replaced by machined positioning pieces integral with the gun body, the magazine having a retaining catch to hold the rounds in place. This control is automatically disengaged when the magazine is fitted onto the gun. Although this idea is a good one, the retaining catch in itself presents a design and functional problem and removal of the magazine can result in spillage of ammunition. This idea was tried in the Italian Breda LMG, the Madsen LMG and the Johnson LMG. It was not practical or popular. The design of Russian and German magazines should be studied, where the lips are reinforced, making them much less vulnerable.

Platform Springs

The platform or magazine spring must be strong enough to feed the last round from the magazine, yet it must not be so strong that the breech block cannot feed the first round from the magazine when the spring is under maximum compression. In the case of the first round the problem is magnified, since the breech block is fired off the sear, having less energy than when functioning during a normal automatic cycle.

Magazine Attachment

The magazine attachment device presents further difficulties because the angle of feed for loading a round from the lips into the chamber is very critical. Any attachment device, which permits excessive movement or displacement of the magazine, will produce a variation in the angle of the feed of a round from the magazine lips and so cause malfunctioning.

Position of Magazine on the Gun

Box magazines may be fitted above, below or on either side of a weapon.

Above

When a magazine is attached above the weapon, it stands directly in the line of sight, so that either the sight has to be offset or the magazine cranked to facilitate sighting. The BREN LMG sighting is offset and the German 20mm Oerlikon HMG Drum type magazine was cranked away from the vertical for this reason. A second disadvantage to mounting the magazine above the weapon is

that it reduces the ability to conceal the gun in the ground role by increasing the height of its silhouette. An advantage is that gravity assists the magazine spring and hence the feed of the weapon is eased when used in a normal ground role.

Below

The underslung magazine is limited in size because of interference from the ground when the weapon is used by the firer in the prone position off a bipod or supported by the hand. For the same reason, removal and replacement can be difficult. The magazine spring has to overcome gravity due to the weight of the rounds when feeding. The concealment of the weapon is made easier in the ground position, since the height of its silhouette is reduced.

Side

A side magazine will tend to upset the vertical balance of the weapon, and this will vary as the magazine empties. The side fitment may affect the handiness of the weapon, making it clumsy to carry and use, particularly bearing in mind that infantry need to carry a weapon with the magazine mounted. For speed in changing magazines, a side fitment may be easier for the firer, particularly in a close quarter weapon that can be fired in the standing position, hence the use of this side fitting on some sub-machine guns.

Recharging Magazines

It has already been pointed out that within the section the feed system, for reasons of speed, ruggedness and reliability, is normally of the magazine type, and that this increases the overall ammunition load of a sub-unit. The alternative would be to recharge the magazine rapidly without detaching it from the gun. This, of course, was the case in most magazine fed bolt action rifles. The ammunition was packed in clips or chargers when manufactured and carried on the man in this form, enabling very speedy replenishment to the rifle magazine and, in fact, enabling a very high volume of fire to be produced even from a hand operated weapon.

Magazine Charging

Fig 12.2 shows a variety of chargers used for rapidly loading different magazines.

These chargers or clips hold the rounds ready positioned for immediate insertion into the magazine, recharging it for continued firing with the minimum of delay. Chargers and clips can be either single column or staggered, as in the case of magazines. The control of the rounds in the devices is similarly critical and is complicated by rimmed cases, which may be forced into the

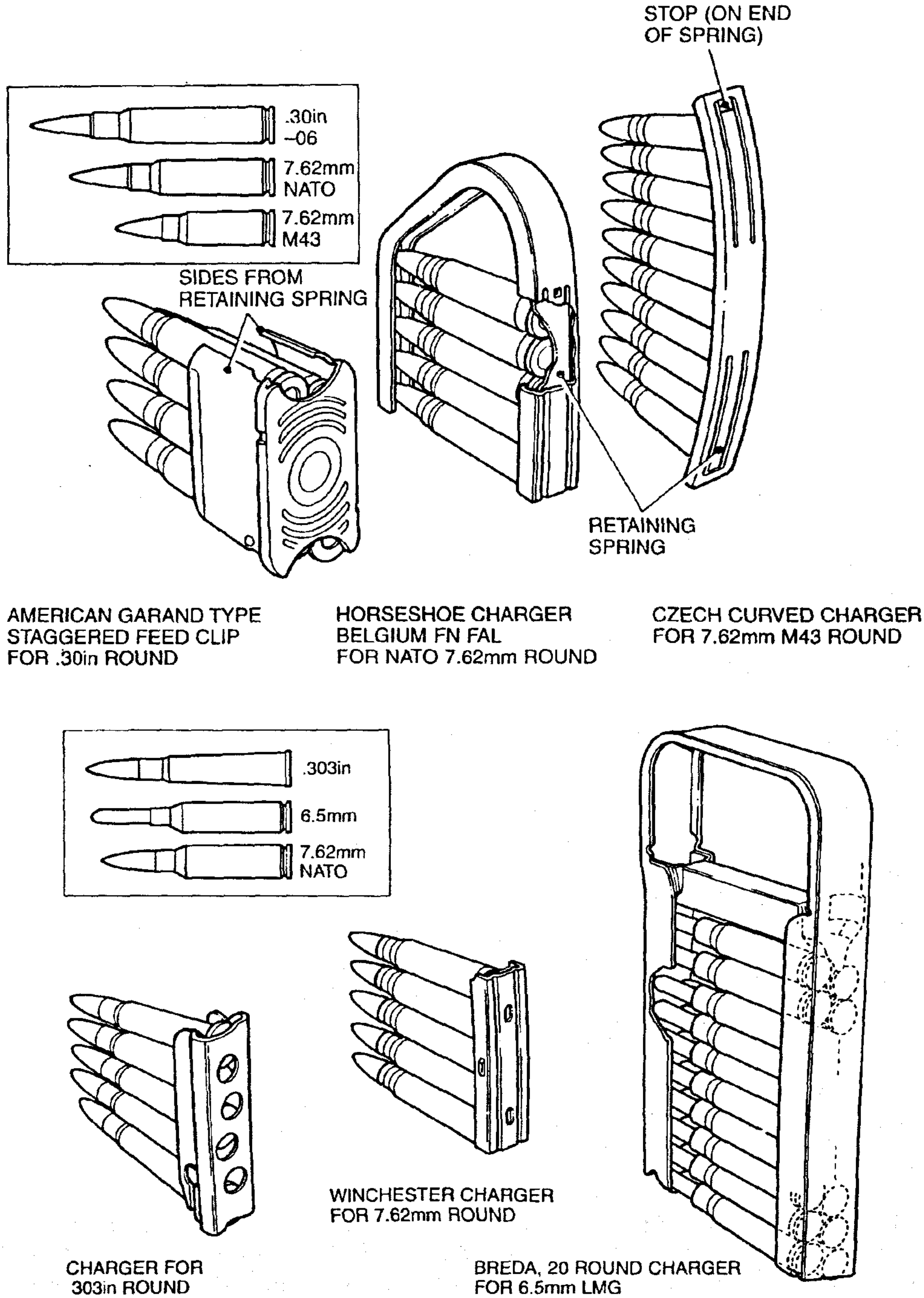


Fig 12.2 Magazine Charging Devices.

magazine rim behind rim whereby overlapping can prevent the feeding of the top round and therefore cause a feed stoppage.

Difference between Chargers and Clips

Chargers and clips are methods of both carrying and positioning the requisite number of rounds for recharging a magazine and are generally factory filled. The difference between a charger and a clip lies in the different functions for recharging a magazine:

Chargers. The charger controls the position of the rounds over the magazine, generally by resting in the guides on the body of the weapon. The rounds are forced straight from the charger into the magazine in one manual operation; the charger is then discarded.

Clips. The clip also controls and positions the rounds. It is forced into the magazine, with the rounds held by it in their correct position and the clip either falls out or is ejected from the magazine when the last round of that particular charge is expended.

Both chargers and clips hold the rounds either by the sides of the case and its base, or simply by gripping the extractor groove of the case. Chargers are more often used with rimmed ammunition. Clips ensure that the rounds do arrive in the magazine in the correct position without the intermediate function of moving from charger to magazine, an action in which the charger may cause incorrect loading. Some types of magazine incorporate an opening for the ejection of the clip, but this may give rise to ingress of dirt and mud into the magazine. As a result of this, some clips are ejected through the mouth of the magazine and weapon ejection opening, or bolt way, in the same way as the empty case, this was done in the American .30in Garand SL Rifle.

It seems quite practical to apply to machine guns the method of recharging magazines normally found in rifles. Some attempts, (notably the Italian Breda LMG), have been made, and an efficient device might be a solution to the problem of feed for LMG systems. Replenishment being carried out with a simple factory filled, waterproof and dirtproof pack.

Drum Magazine, Gun Driven

The gun driven drum magazine is rare today. The basis is a shallow flat drum, working in a horizontal position on top of the weapon, with its axis at right angles to the barrel of the gun. It is sometimes called a 'Pan' and contains no spring but is driven by a feed pawl on the gun.

The rounds are placed radially and are held by either the rim or groove and separator pins. The bullet points fit into a spiral guide which causes the rounds,

as the feed mechanism rotates the pan about the axis, to move radially down round the spiral to the magazine feed opening. Serrations are formed round the periphery of the pan in which the feed pawl engages, the cartridges are removed by a feed piece operated by the gun.

The advantages of this magazine are:

- Simplicity.
- No magazine spring with its inherent problems.

The disadvantage of this magazine is the complicated gun feed mechanism necessary to operate the magazine feed system, which includes two additional pawls; one to prevent over-rotation and the other to prevent the drag back of the drum causing counter rotation, both of which may cause malfunctioning. If any of these small pawl springs break, a feed stoppage will occur and, further, these small parts are easily lost during stripping in the field. Fig 12.3 shows the gun driven drum magazine fitted to the Lewis gun.

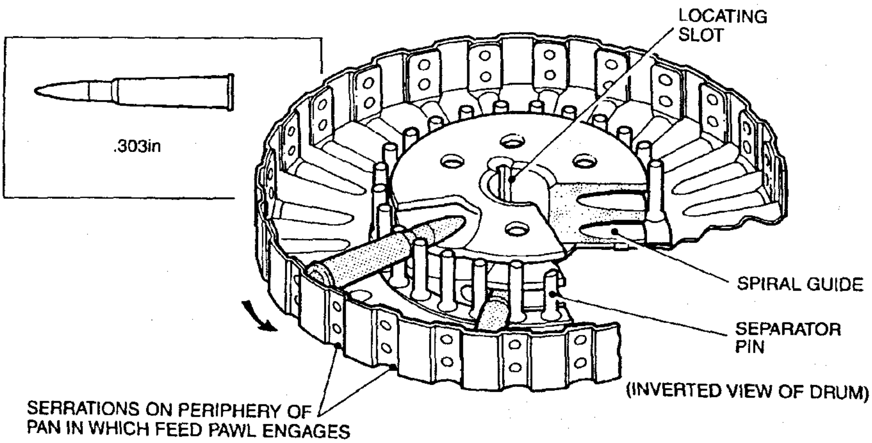


Fig 12.3 Gun Driven Drum Magazine, .303in Lewis LMG

The Lewis gun is the best example of this type of feed system. The ground version held 47 rounds in two layers and the air pattern drum held 97 rounds in four layers.

Drum Magazine, Spring Driven

The main difference between the spring driven drum magazine and the previous type is that, in this case, the rounds are fed out of the magazine by a spring loaded follower instead of being operated by the gun. The spring driven magazine is found in two distinct forms: one where the rounds are held in

position radially and the other type axially. In the radial type, the rounds lie at right angles to the axis of the magazine, completely filling both the larger arc at the maximum diameter and the smaller arc nearer the axis. In the axial type, the rounds lie parallel to the axis of the magazine and in some cases these magazines are similar in form to a truncated cone to achieve the minimum weight. Since the rounds have varying degrees of taper, the base end has a larger diameter than the bullet end.

The effect of these two methods is to provide an alternative to a shallow, large diameter drum like a pan that is difficult for an infantry soldier to carry. A smaller diameter, more compact drum is easier to accommodate in either the infantryman's equipment or a container. No drum type magazine is very economical on space, due to the circular form and, consequently, it is not often found on infantry weapons for use in the ground role. It does provide, however, a compromise between the box magazine and belt feed in its ammunition capacity and retains the characteristics of magazine feed. It is sometimes used for heavy machine guns operating in the ground to air role, enabling them to have an alternative feed with a box magazine if required for other roles. A similar idea, except that the magazine drum has been elongated, is that shown in Fig 12.4 for the US Calico 9mm helical feed system.

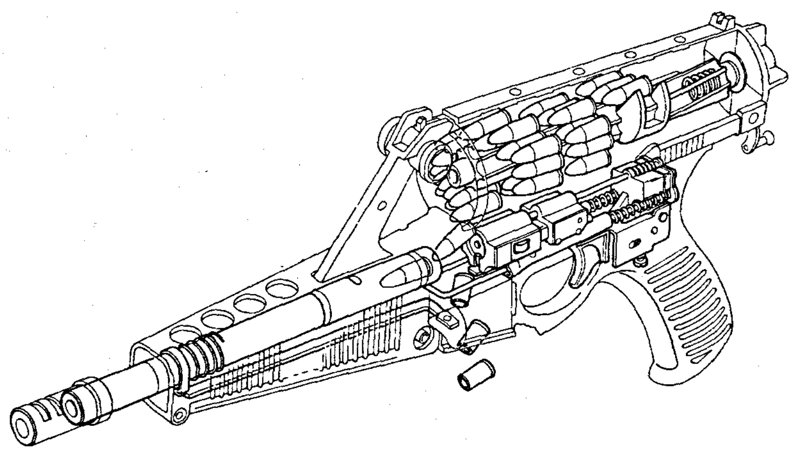


Fig 12.4 Calico Helical Magazine.

The magazine springs are usually of the clock type and may be wound up after loading, a method which is desirable in the larger capacity types to facilitate filling, which would otherwise require overcoming the very powerful magazine spring. Where it is not possible to wind the spring afterwards, it is nearly always possible to hand operate it during magazine filling, thus relieving the tension. The capacity of this type of magazine varies from between 50 and 100 rounds. It is therefore normally designed for, and fitted to, machine guns which may be required to fire longer bursts than can be supplied by the normal box

type of magazine, though they can still accommodate the latter if required for other roles.

It is claimed that the difficulty of feeding out the first round of a full magazine in the box type does not always occur with the drum, since the friction between the rounds and their guides absorbs the surplus spring pressure. The friction diminishes progressively as the drum empties and the spring pressure weakens, thus achieving an automatic balance to the magazine spring loading. An indicator is generally included in the design of drum type magazines to show the number of rounds remaining. This is achieved by drilling holes at suitable points and stamping the number of rounds remaining if the ammunition can be seen at that point. But this method does permit an ingress of dirt and mud and is not therefore desirable for use in ground roles. A more modern way is to make the back, or some other part of the magazine, in 'see through' plastic.

Examples of Spring Driven Drum Magazines

All the same design problems are present in the drum type magazine as the box type. They are complicated by the circular shape of the magazine that makes the positioning of the rounds even more difficult, and by the strength of the magazine spring, necessary for the greater capacity of the magazine, increasing the frictional problems. Drum type magazines are difficult to fill, and normally take longer than a box type allowing for the difference in capacity. The limitations of this type of magazine, make it unpopular for use in the ground role on infantry machine guns. Fig 12.5 shows the spring driven drum magazine used with the Thomson SMG.

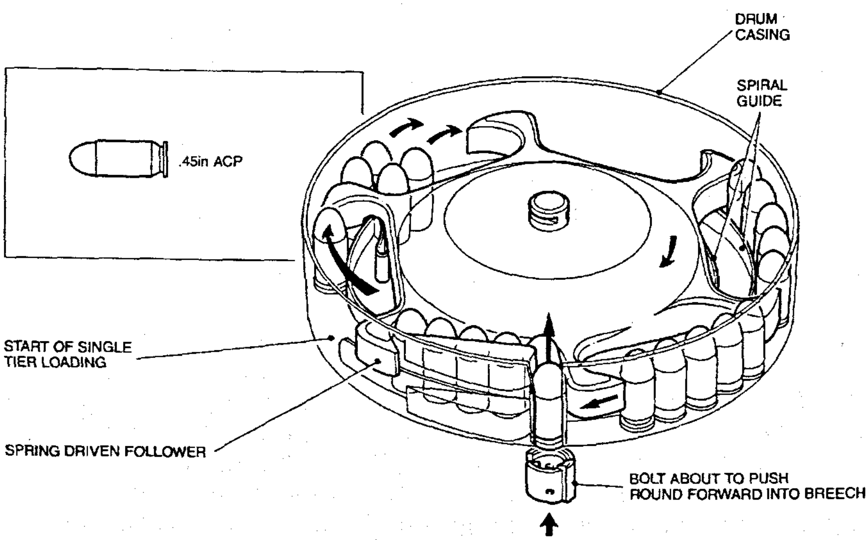


Fig 12.5 Spring Driven Drum Magazine, Thompson SMG

There are a number of spring loaded magazines where the spring can be wound or released at will. Such a magazine is fitted to the Calico weapons from the USA.

Double Drum or Saddle Type

The Germans applied the principle of a saddle form magazine, with a drum on each side of the gun, to their MG34, shown in Fig 12.6, which reduced the height of the silhouette of the gun with overhead feed and, at the same time, retain a balance. The two drums with a bridge piece formed one unit, and the cartridges were fed one round from each drum alternatively. Clock type springs were fitted and were permanently wound, but for ease of loading a key was used to relieve the pressure. The Germans used this type for a time in ground role machine guns, but later on in World War II, it was replaced by the MG42 with belt feed system only. The MG34 on which the saddle type was employed, could use either magazine or belt feed by changing the feed cover. A more modern and lighter design based on the same configuration, called the 'C Mag' is available. It was made to give the M16A2 an 100 round magazine capacity.

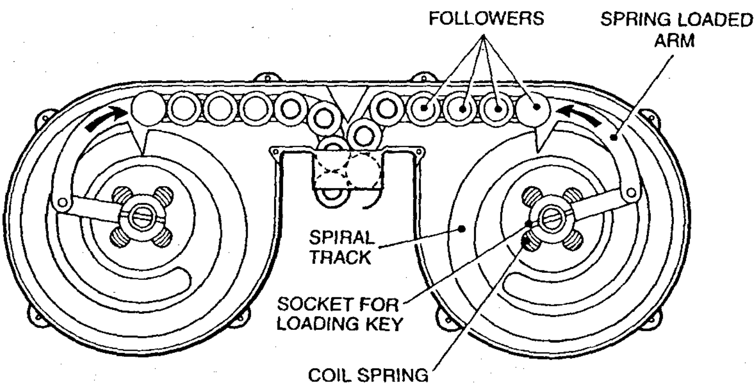


Fig 12.6 Double Drum or Saddle Magazine, MG34

Tubular Magazine

Before the advent of bullets with a sharp pointed nose, the tubular magazine was both popular and in common use in rifle type weapons. It consisted of a tube which held the rounds one in front of the other; it was normally attached parallel to the barrel and contained a spring to force the rounds towards the breech opening. With the introduction of centre fire cartridges and pointed bullets, this type of magazine became unsafe under certain conditions. The bullet points could indent the cap of the round in front sufficiently to cause the primer to explode, but the principle is still to be found on some of the older type service rifles such as the French Lebel Rifle Model 1886.

The tubular type of magazine is still used for weapons using rim fire cartridges such as the .22in rifle and where sharp pointed bullets are not used, as with some sporting rifles and shotguns. It may be situated either under the barrel or in the butt of the weapon.

Belt Type Feeds

It has already been shown that belts are normally used for machine guns where a sustained feed is required. This system is generally applied to GPMGs, medium machine guns and machine guns used in tanks, which require sustained bursts and have the capacity for belt installations.

If the size of the vehicle permits, an indefinite length of belt may be used and a suitable mechanism installed to feed the belt to the gun. The length of belt that a gun can itself operate is limited by the energy the gun has available for this purpose. But mechanical assistance by some external force, generally an electric motor, will permit the use of longer lengths. By this method bursts of fire can be made without failures for as long as the design of the gun will permit.

A belt can be made lighter than a magazine holding an equivalent number of rounds, but once out of its container it is vulnerable to mud and dirt, so that for transportation it is sealed in a watertight pack which increases the overall weight.

Belt systems may be constructed in fabric, metal, or a combination of both. They may be full length, disintegrating link by link, or fabricated in shorter lengths (usually of about 25 rounds) which can be joined together to make up a long belt if required.

In the fabric type and some older disintegrating link belts it is necessary to arrange for the cartridge to be extracted rearwards. This is particularly true with rimmed ammunition. The cartridge is contained in a complete pocket, hence the title 'closed belt'; an example of this mechanism and system is found on the Vickers MG. The modern trend is towards an open type disintegrating link belt combined with a rimless case, which enables the round to be pushed through the link direct into the chamber by the bolt. This requires less feed mechanism and is better suited to high rates of fire. An example of this system is found on both the German GPMG, the MG3, and the British L7A2 GPMG.

Belts containing fabrics must be proofed against rot, fungus, damp and every other possible form of environmental attack. It is also an essential requirement that they should not alter in length to any appreciable extent. Metal belts impose a more constant frictional load than fabric and the energy drawn from the gun for feeding is therefore more even.

Fabric Belts with Metal Strips

This type of belt was the original used for the Vickers MG. The belts were woven in one piece, no stitching being required to form the pockets, which were partitioned by brass strips riveted across the belt. Every third strip was longer than the other two in order to project beyond the width of the belt on the same side as the bullet, to prevent the round from being displaced during transit and to position the belt accurately in the feed piece on the gun. These belts were relatively expensive to manufacture and were therefore considered part of the gun stores. Other countries have used this type without the prolonged strip, notably Austria on the Schwarzlose MG.

Plain Fabric Belts

The stripless fabric belt was introduced to provide factory filled belts, which were expendable and therefore avoided belt filling in the field. The belt was packed in a watertight tinplate box at the filling factory and millboard packing pieces were used to prevent it from working forward off the cartridges. These belts had stitched pockets with no metal strips and the fit of the round was therefore very susceptible to any change that might occur in the belt material by reason of moisture or climatic conditions. Once used, even if salvaged, it was very difficult to refill, due to its being stretched during firing and thus very difficult to load evenly.

Metal Belts

From a functional point of view, a metal type belt has several advantages. The positioning of the rounds is consistent, it is not affected by either rot, nor atmospheric and climatic changes. Metal is a better working medium, if correctly made, than fabric. On the other hand, a metal belt is more costly and difficult to manufacture, best results being obtained with spring steel which is usually in short supply in wartime. Weight for weight, for a given number of rounds, a metal belt (even of light spring steel) is heavier than a fabric belt. Light alloy belts have not proved sufficiently strong for service use except where their section is such as to lose all the advantage of weight saving. Light alloys can be used in conjunction with fabric that provides the additional strength required.

The best belts are undoubtedly metal. There are two types in common use:

- The continuous metal belt.
- The disintegrating link belt.

Continuous

The continuous metal belt contains pockets for 50 rounds with the facility for

joining the ends of two belts, using a cartridge as a hinge pin, to make a long length when continuous fire is required. This system was originally developed for the German dual purpose machine gun the MG34 and continued in the MG42. It is now used by the Soviets in their light machine gun, the RPD, and in their medium machine gun, the SGM, or Goryunov M43. The spring steel links have to be accurately formed to provide for the control of the belt in the feed mechanism and the links have to be joined in such a way that they can bend in two planes at right angles. This allows folding of the belt in containers and also allows flexibility in the belt when the gun is firing in elevation or depression. The join normally takes the form of a small coil spring. The round is positioned in the link by the groove engaging a pip on a nib extending from the link itself. Empty belts can be filled in the field using a filling machine or by hand. However a link can become damaged and this makes the whole belt of limited value.

Disintegrating

The disintegrating link has been accepted by NATO as a standard for both 7.62mm and 5.56mm ammunition. The cartridges pass through two links shown in Fig. 12.7. The rim is positioned by a pip and when the round is forced forward into the chamber, it is pushed out of the link which is then free to be ejected from the gun. The links fall to the ground, or in a tank machine gun into a bag, but it is not intended that belts should be made up in the field from links that have already been used, although this is possible. Used links are bound to be suspect and can lead to stoppages. This system allows a flexible belt that may be twisted or spread fanwise to suit feedways and gun entries.

Earlier systems used 'closed pockets' in which the round had to be withdrawn rearwards before being fed forwards into the chamber. These are now obsolescent, although the Russian PKD and PKT machine guns still use such a belt because of the rimmed nature of ammunition. It should be noted that the current disintegrating link belt is expensive to produce, cannot readily be used more than once and the discarded link itself can easily cause a stoppage. Different belt and links are shown in Fig 12.7.

Belt Tongues

Many belts require some form of rigid tongue at the loading end to facilitate the initial feeding of the belt into the feed mechanism of the gun. This tongue may be either metal, plastic, leather or simply a stiffening of the fabric by some substance like resin. Very often these tongues are provided with a wire loop as well to make for ease of drawing the end of the belt out of its container.

Design Problems in Belt Feeds

The main design problems for belt systems are:

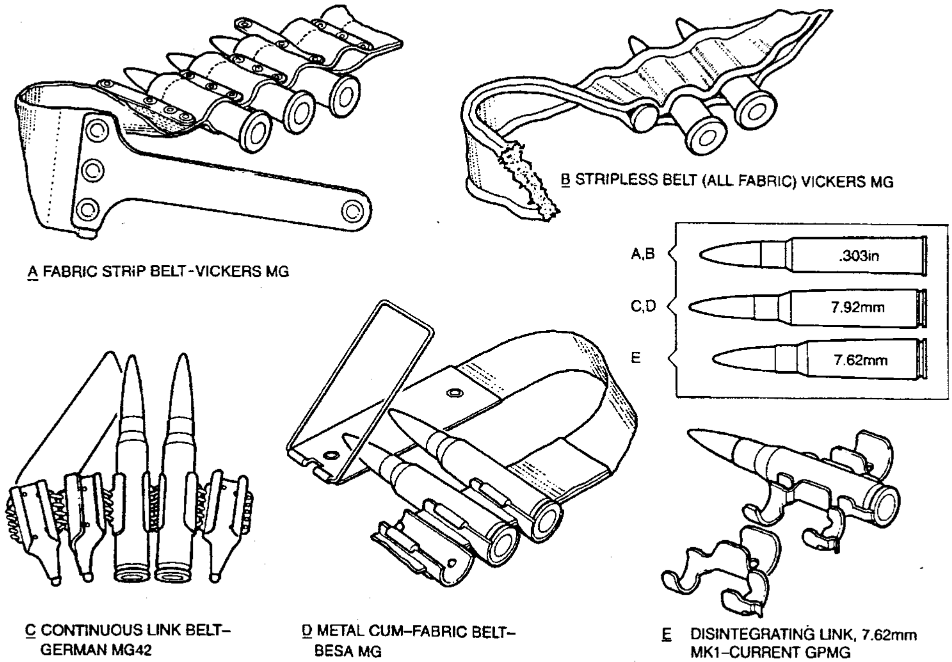


Fig 12.7 Belts and Links.

- The control of the round in the belt.
- The consistency of the fit of the round in the belt.
- The strength of the belt under loaded conditions.
- The serviceability of the belt under all conditions.
- The flexibility of the belt, both fanwise and twisting.
- The weight of the belt.
- The manufacture of the belt.
- The control of the link after the round is fed.

Strip Feed

The strip method of feed was an early compromise between belt and magazine systems. Typical examples are shown in Fig 12.8. As the name implies, this system was made from a strip of metal sufficiently stiff to support the

ammunition it contained in one plane. The strip contained a series of clips to hold the rounds longitudinally across its width; these were either formed by pressing clips out of the surface of the strip, or by a series of metal partitions clipped on to the surface on one side of the strip. Normally a strip feed accommodated only about 25 rounds due to handling difficulties and the fact that larger numbers would cause the strip to bend with consequent malfunctioning of the gun, unless the strip had considerable section for additional strength. The problems of positioning this system to the gun were similar to those enumerated for magazine fitment. Further, allowance had to be made for the strip on the exit side of the feed block whence it travelled as the rounds were fired.

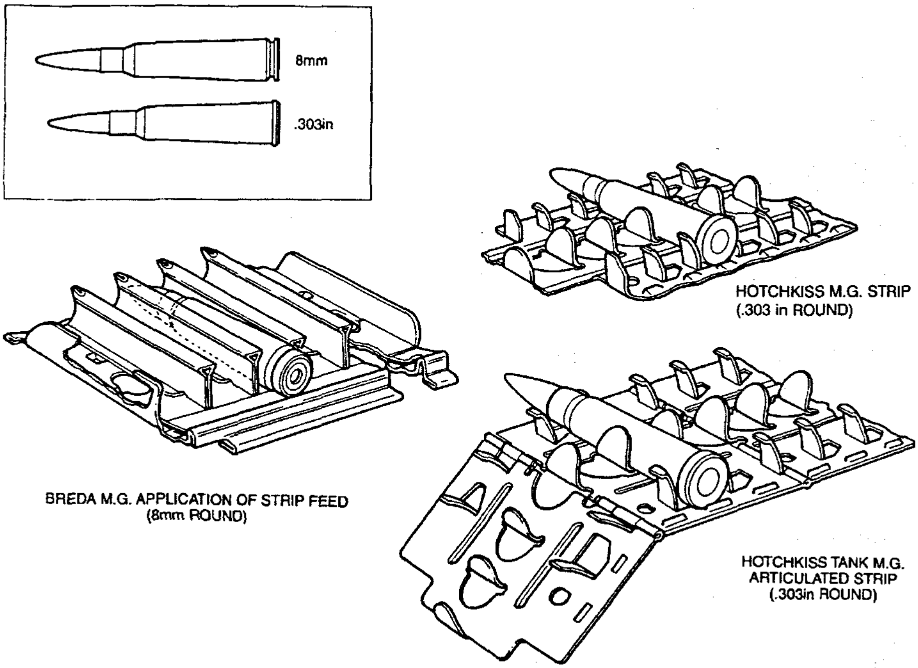


Fig 12.8 Strip Feed Mechanisms.

Both flat and articulated strips have been in service. The Hotchkiss machine gun used flat strips with an open type clip to enable the round to be pushed forward into the chamber. The Breda LMG had partitions fixed to the strip to form clips for the rounds. These not only held the unfired rounds, but accepted the empty cases on the unloading stroke of the bolt. Strips, although light, were easily damaged or deformed, were difficult to protect whilst the gun was being carried and projected from the gun and increased the space required inside an AFV. Such systems are no longer used.

Feed Mechanisms

Of all the mechanisms, only the magazine causes the round to be positioned ready for loading into the chamber. Belt and strip conveyors are simply a system for holding the ammunition correctly attached to the gun and the operation which causes the round to be positioned for loading by moving the conveyor, is carried out by an additional mechanism known as the 'Feed Mechanism'.

Feed mechanisms may be operated either by the weapon, or by a spring, or some source of energy external to the gun and these form the three basic types of mechanism under which this subject will be considered.

- 'Gun Driven' feed mechanisms.
- 'Spring Driven' feed mechanisms.
- 'External Source Driven' feed mechanisms.

Gun Driven Feed Mechanisms

In the gun driven feed mechanisms, use is made of the energy available to drive the gun, and the mechanism is normally operated by one of the reciprocating parts of the gun as an addition to, and part of, its normal operating cycle. This energy is limited, particularly in 'recoil' and 'case projection' systems and, therefore, the work the feed mechanism can do is restricted, in particular with regard to the weight of the conveyor and ammunition it can move or lift. The type of conveyor and the number of rounds it can hold and the positioning of belt boxes or feeds in relation to the gun, are all interrelated to the system of operation of the gun and the energy available to drive the feed mechanism. This is a very important consideration when designing a gun for certain roles and specifications. The conveyor feeds the ammunition at right angles to the movement of the reciprocating parts of the gun and, as a result, the method of operating the feed mechanism is always very similar.

In the earlier guns the reciprocating part, usually the barrel extension or side plate, operated a cranked feed lever which pulled the belt across the gun. This was found in short recoil operated weapons such as the Vickers MMG, shown in Fig 12.9. In later weapons, regardless of the type of operation, there is an almost universal application of the system first developed by the Germans in which the reciprocating bolt carries a roller running in a curved groove in the feed arm located in the top cover plate of the gun. There is a variant to this system in which the curved groove is located on the reciprocating part and a follower is mounted on the feed arm in the top cover plate, as in the Browning MG.

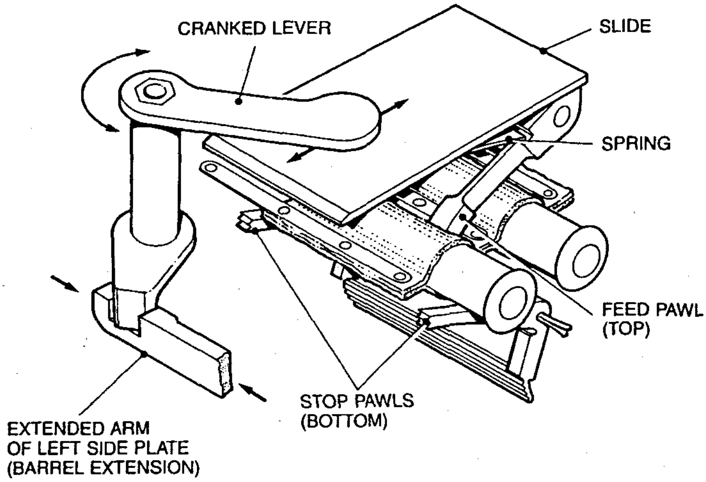


Fig 12.9 Gun Driven Feed Mechanism, Vickers MMG

The feed is operated by a cranked lever, one end of which is operated by the sideplates (barrel extension) of the gun, which recoil only a short distance. The other end of the lever operates the feed mechanism, feeding the belt across the gun. The belt is checked and positioned by pawls, but since a 'closed' type of belt is used, the round has to be withdrawn rearwards before loading. The withdrawal of the round from the belt is carried out by an extractor slide.

As the breech block extracts the fired case from the chamber, the upper portion of the extractor withdraws a fresh round from the belt. This extractor slide is operated by the reciprocating movement of the working parts, so that the fresh round is lowered into position ready to be pushed into the chamber on the loading stroke. This mechanism is complicated, the belt being positioned by energy from the recoiling portions and the round being withdrawn from the belt and positioned for loading by the breech block cycle.

The current British GPMG, the L7A2, uses a system originally employed in the German MG42 and, subsequently, the German MG3 GPMG as shown in Fig 12.10. The bolt carries a feed actuating roller that works in the groove of a curved feed arm. Attached directly to the end of the feed arm is a short, centrally pivoted, lever carrying two sets of pawls. The forward end of the lever carries an inner pawl and the rear end supports the outer pawls. Since these two sets of pawls are on opposite sides of the central pivot, they will always be moving across the gun in opposite directions. This is shown in the drawing in Fig 12.10.

In diagram 'A', the gun is cocked and the round is held up to the feed way by the inner pawl. The outer pawls are positioned behind the second round.

In diagram 'B' the bolt moves forward. But since the actuating roller is moving

down a straight section of the feed arm, there is no movement of the pawls and the round is pushed forward out of the belt. The nose of the round encounters the bullet guide that deflects it down into the chamber. It is obviously essential that no movement of the belt occurs whilst the round is being pushed out.

In diagram 'C', the roller has moved along the curved portion of the cam path of the feed arm which has been forced across to the right. This has moved the inner pawl out and the outer pawls inwards. The inner pawls are spring loaded and thus ride over the round being moved in by the outer pawls. At the moment of firing the first round, the inner and outer pawls are jointly positioned behind the second round.

In diagram 'D', the rearward movement of the actuating roller has pulled the feed arm fully across to the left. The inner feed pawl has taken the second round across to the axis of the bore and holds it ready for chambering. The outer pawls have moved out and positioned themselves behind the third round.

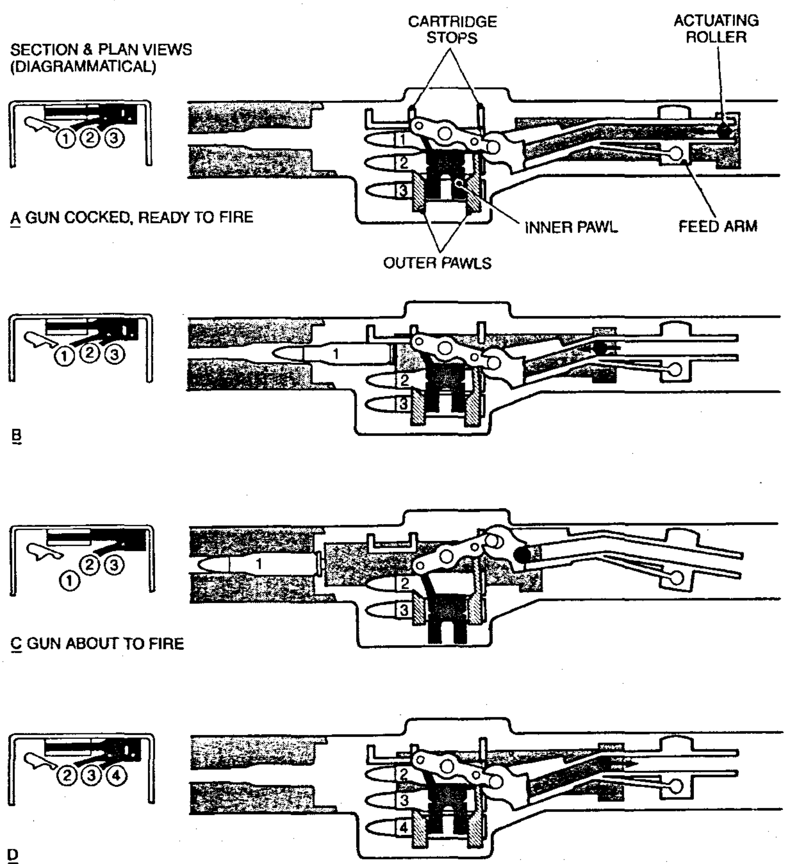


Fig 12.10 Gun Driven Feed Mechanism, 7.62mm L7A2, GPMG

The basic method of operation is simple, but there are certain advantages obtained from this particular pawl arrangement, in which the outer pawls bring the round across by a distance equal to half a round pitch and then the inner pawls move it in the other half pitch. These short movements reduce the accelerating forces on the pawls and lead to a smoother action because the belt is fed through the gun on both the backward and forward movements of the bolt. The previous example of the Vickers gun is different where all the feed movement occurs whilst the breech block is moving back.

An example of the mechanism where the breech block carries a cam path and the feed arm follows that path, is the French GPMG, the AA52, shown in Fig 12.11. This is a delayed, blow back operated gun in which the two parts of the breech block separate and so a roller cannot be used. Instead, a bar is used to bridge the gap and follow the cam curve. Instead of having inner and outer pawls, this French gun uses only one set of feed pawls and, therefore, unlike the L7A2, needs to have stop pawls to hold up the belt whilst the feed pawls are moving out to collect the next cartridge, prior to dragging it across.

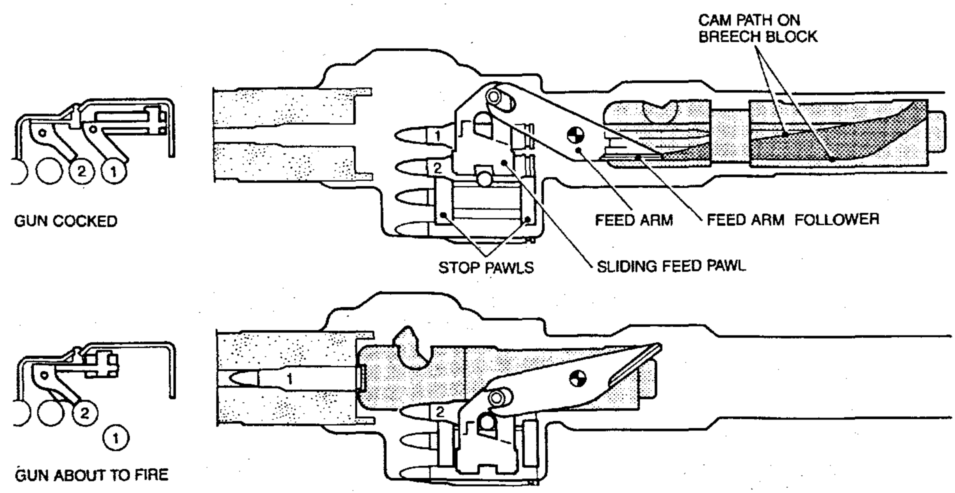


Fig 12.11 Feed Mechanism, 7.5mm French AA52 GPMG

In the previous examples, the bolt has actuated the feed mechanism because the roller is mounted on it in the L7A2 and the cam path has been cut in it in the AA52. However, the feed mechanism can equally well be controlled by the piston in a gas operated gun.

An example is taken from the Russian MMG, the M43, designed by Goryunov, shown in Fig 12.12. Here the piston carries grooves set across the flat top of the extension. A feed piece or feed slide has mating key surfaces to fit into the grooves so that, as the piston reciprocates, the feed slide moves across from

right to left and back again. There is a spring loaded feed pawl mounted on the slide which pulls the belt across, as the piston moves back, and positions the round, ready for it to be gripped in the feed claws. As the piston comes forward, the pawl slips under the rounds which are held up by stop pawls and positions itself for the next feeding stroke.

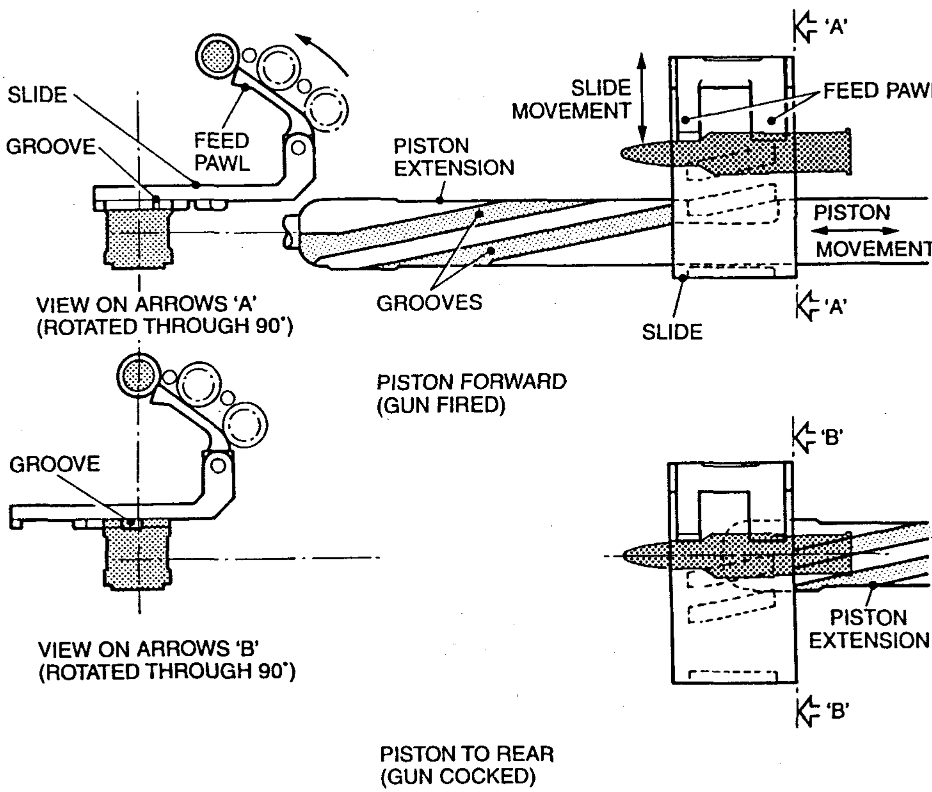


Fig 12.12 Gun Driven Feed Mechanism, Goryunov M43

Another rather more elegant way of using the piston is employed in the Czech LMG, the Vz 52, shown in Fig 12.13. Here the piston carries two cam paths, one above the other, on the right hand side. A pivoted follower is controlled by these two cam paths and oscillates across the gun body with a spring loaded pawl pushing the belt from right to left as the piston comes back and slipping under the belt as the piston goes forward.

Alternative Feeds

It is unusual to require a gun to have more than one feed system, but, where it exists, the usual requirement is that the gun should be capable of firing with

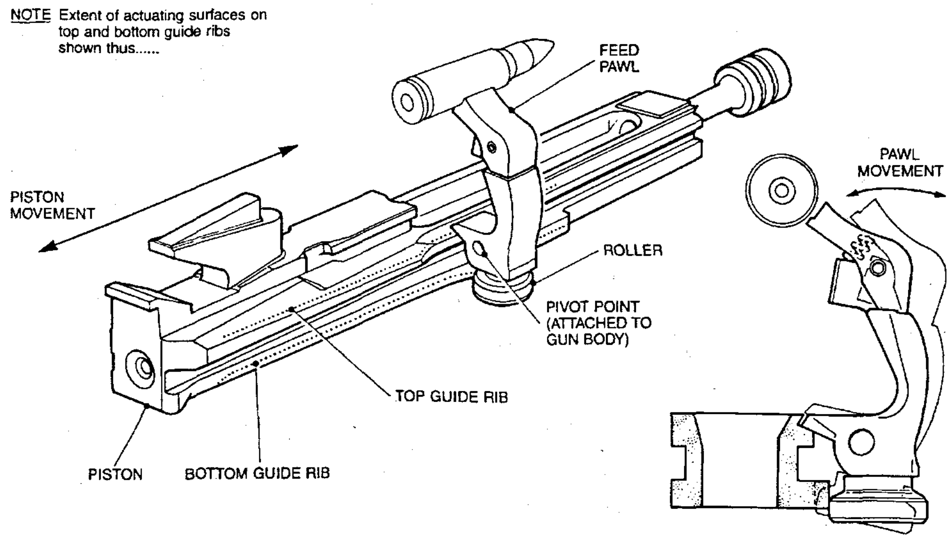


Fig 12.13 Gun Driven Feed Mechanism, Czech Vz 52

its ammunition fed either from a magazine or from a belt. This may be required because the tactical role is changed, as will frequently happen with a GPMG, or that ammunition for other guns is available in a different conveyor. There are a few guns, of which the Czech Vz 52 is an example, which have a feed mechanism suitable for either method of supply. The FN Minimi fires linked belts for preference but can take any standard 5.56mm magazine without any change to the mechanism. However, it must be remembered that the energy required to pull a belt and de-link it, is now in excess and results in a more difficult gun to control. The majority taking both belt and magazine, or belt and drum, require some part of the feed mechanism to be removed for drum feed and replaced for belt feed. A typical example is the Russian machine gun the RP-46.

Sometimes there is a need for a gun to fire different kinds of ammunition at will. For example, a gun may generally use HE ammunition but need to change over to Armour Piercing at short notice. This problem can be met by introducing dual or even triple feed systems, sometimes using magazines, sometimes belts, sometimes both, with the ability to switch from one to the other as the requirement changes. Fig 12.14 is from the German Rheinmetall Mk 20 Rh 202, 20mm gun.

Revolver Guns

Aircraft machine guns were of rifle calibre until, during WW2, heavy machine guns of 20mm size were employed. The great increase in flying speeds and the consequent short engagement time made it imperative that the rate of fire should be increased.

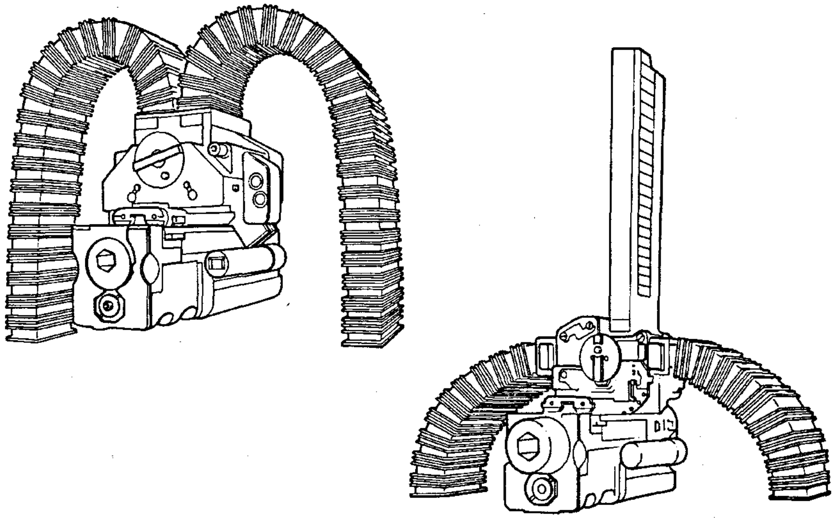


Fig 12.14 Alternative Feed Systems, Rheinmetall Mk 20 Rh202

Several ways of doing this were tried but eventually only two types of high speed heavy machine guns came into service. These were the revolver gun and the multi-barrel, or Gatling type gun. The latter will be discussed later as an externally powered gun. The ADEN 30mm Aircraft Cannon is derived directly from a war time German Mauser design. It fires at a rate of 1200 rpm using a revolving cylinder with five chambers into which rounds are fed by stages and finally discharged through a single barrel.

The ammunition feed is of the disintegrating belt type with open pockets and the links joined by hooks and eyes. The belt is loaded into the gun by hand and fed into the starting position by a pneumatic cocking unit. The gun is electrically fired and gas operated. After the first round is fired, the sequence is as follows, as illustrated in Fig 12.15. The gas is vented off to drive back a piston that, in turn, drives back two slides which are coupled by a connecting rod. The front slide carries a lever with a cam path and the rear slide comprises a two stage rammer. As the front slide moves back, the cam path picks up one of five rollers and rotates the cylinder through 36°. As the front slide goes forward, the cylinder rotates a further 36°. The breech cylinder does not rotate at the beginning or end of the slide cycle because a straight groove in the slide engages the roller. This ensures that the breech cylinder does not rotate during the ejection of the empty cartridge case and the chamber is aligned with the bore when the gun fires and the projectile leaves the chamber.

The cylinder does not start to rotate until after the projectile has left the muzzle and the gas pressure has dropped to a safe level.

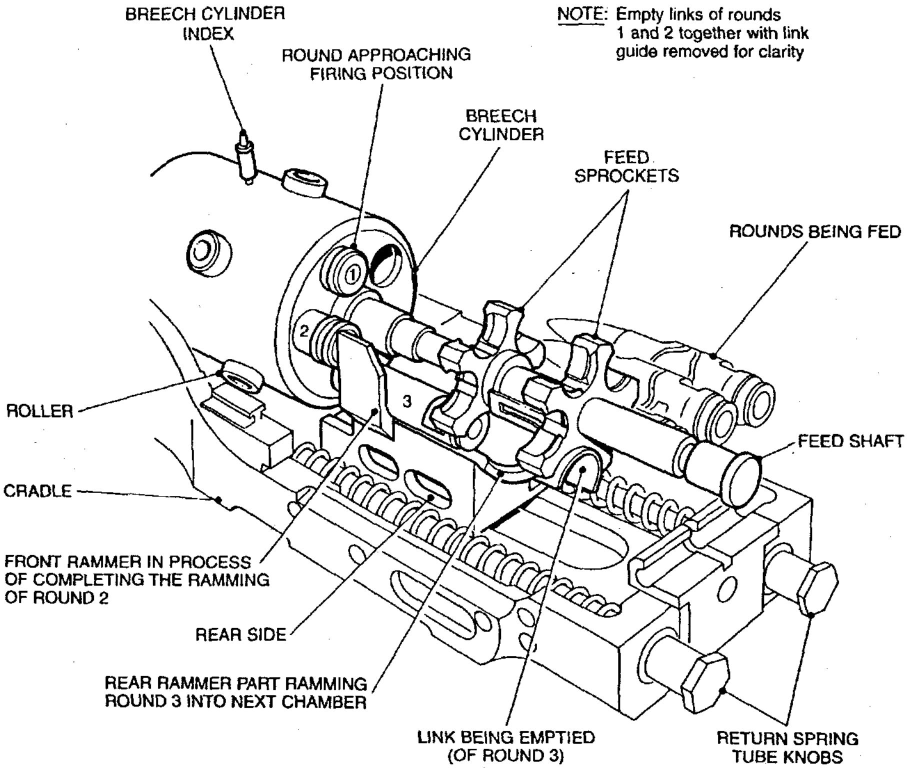


Fig 12.15 Revolver Gun Feed Mechanism, 30mm ADEN

At the front of each of the five chambers in the breech cylinder, is a metal sealing sleeve which seals against the barrel face to provide obturation and prevent gas escaping from between the front face of the breech cylinder and the breech face of the barrel. Mounted on a prolongation of the shaft on which the cylinder revolves, are two feed sprockets. During the rearward travel of the slides, the cylinder and sprockets rotate through 36° and the sprockets position a round in front of the rear rammer. As the slides go forward, the rammer drives a round out of the link and partly into the chamber which is at the 7 o'clock position. The feed link is then pushed up the guides and ejected vertically. On the next rearward stroke of the piston, the cylinder carrying the partly fed round rotates into the 8 o'clock position and the forward movement of the slide continues the rotation of the cylinder, and brings the forward rammer against the base of the round to complete the chambering. On the next forward motion of the piston, the round reaches 12 o'clock and is fired electrically. The empty case is ejected towards the end of the next forward stroke of the slides, whilst the roller is in the straight portion of the cam path.

From this lengthy description it can be seen that the revolver gun is complex. The inertial forces involved are high and ramming has to be carried out in two

stages, which means that on initial loading the pneumatic cocking device must be operated three times to bring a round to the firing position.

In summary it can be seen that:

- The first stroke causes the first round in the belt to be partly rammed.

- The next stroke causes the complete ramming of the first round and partial ramming of the second.

- The third stroke brings the first round into the firing position, rams home the second round and partly rams the third round.

The gun was originally designed to have two types of barrel. One for high velocity rounds fired at 790 m/s and the other for low velocity rounds at 610 m/s. The HV barrel is not now a standard issue. The Tornado mounts a Mauser 27mm cannon of similar design. The Harrier GR7 uses a 25mm ADEN, designed on the same lines, but with a longer barrel and is mechanically fired with a maximum rate of fire of 1850 rpm.

Design Problems, Gun Driven Feed Mechanisms

The following factors have to be considered when designing a gun for a gun driven feed mechanism:

- The type of feed system to be used.

- The amount of energy required to drive the mechanism for the feed.

- The amount of energy that can be provided by the type of operation for the particular gun.

- The cyclic rate of fire required.

- The number of rounds and weight of conveyor required to be moved and lifted by the feed mechanism.

- Whether any external source of energy is available for assisting the feed mechanism.

- The type of conveyor to be used, ('open' or 'closed' belts, disintegrating links etc).

- The type of ammunition to be used and any alternative required.

- The role for which the weapon is required.

- Any particular mounting or installation restrictions.

Spring Driven Feed Mechanisms

With a spring driven feed mechanism, the operating energy comes from a spring and not from the surplus energy derived from the propellant. It can be external in relation to the gun body.

When a spring is used, the rounds must be fed across. The spring energy so used must be replenished by the gun itself. Thus indirectly the feed can be said to be operated by the gun even though a spring is interposed. There have been examples in the past such as the Manlicher Schoenaur rifle, and the 20mm Hispano which used a spring loaded system to adapt a gun basically designed for magazine feed to belt supply. The main drawback to such feed mechanisms is that in conditions of dirt and dust where friction forces increase, there is no reserve of energy. In circumstances where gravitational forces have some effect, the spring may be inadequate. Modern practice does not accept this method, but prefers more positive control of the feed arrangements.

External Source Driven Feed Mechanism

Any available source of energy can be used to power the externally driven feed mechanism. It can be electrical, mechanical, hydraulic or pneumatic. All of these have been used with one weapon or another in tanks, aircraft and boats. Until recently there has been little interest in land service in such devices because they have added to the weight and complexity of the system, without contributing increased efficiency. The war in Vietnam focused attention on the multi-barrel Gatling type gun which itself is externally powered and uses further electric motors to feed the ammunition to the gun. Since the method of feed is basically that of the Gatling, the principle of feeding can best be shown in Fig 12.16.

The Gatling type gun, is specifically designed to fire at a high cyclic rate and to accomplish this it has a number of barrels that are rotated and fed by an external source, usually an electric motor.

Each barrel has its own bolt that locks into the barrel extension and each bolt has its own firing pin. The round is picked up by the bolt, gripped by the extractor and carried around. At the same time the bolt is forced forward and the round enters its own chamber. The bolt is locked and the firing pin cocked by being held on a cam path as the bolt goes forward. At the end of the cam path the firing pin is released, flies forward and contacts the cap. Firing takes place at the 12 o'clock position. The bolt subsequently runs along the dwell segment of the cam path and this provides the mechanical safety after firing. The bolt is subsequently unlocked and withdrawn for extraction and ejection to take place.

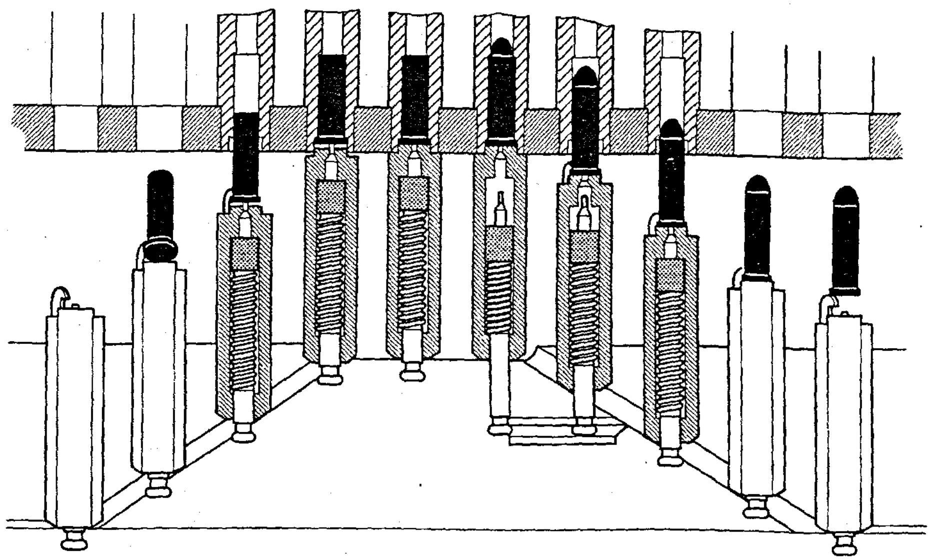


Fig 12.16 Feed System of the Gatling Gun.

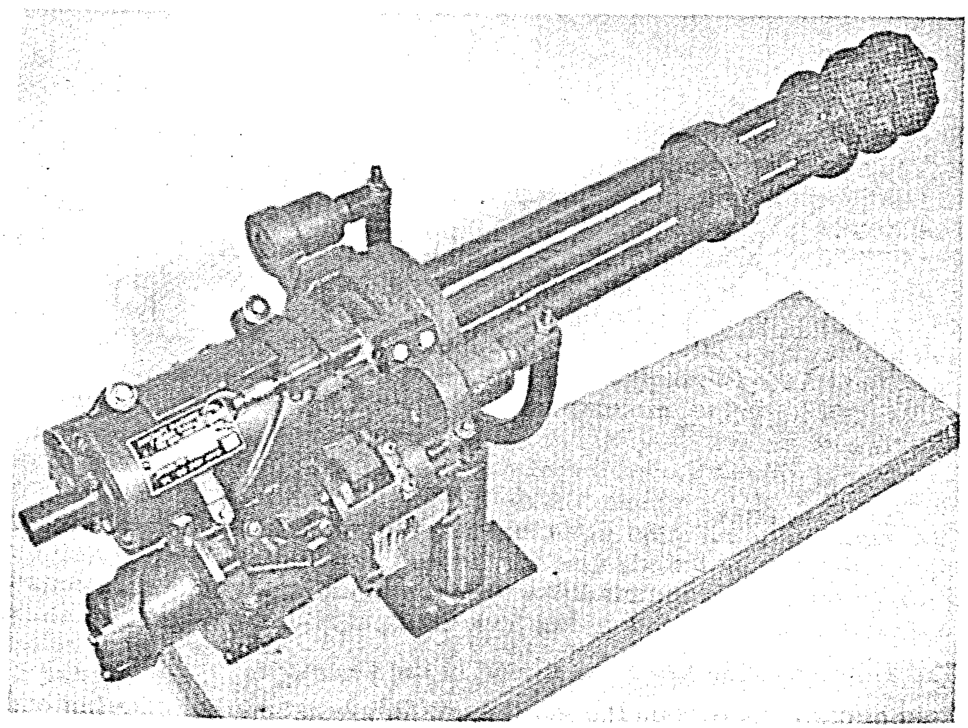


Fig 12.17 The GEC Minigun

The modern, six barrelled Vulcan 20mm cannon and the 7.62mm Minigun shown in Fig 12.17, can fire up to 6000rpm. In order to do this the ammunition is led along a duct and electric motors are placed at the mouth of the storage bin and also near to the gun. There is a separate motor rotating the barrels and this requires a steady 70 amp supply to maintain 4000rpm with twice that amperage required for starting. The ammunition may be either linked or link less. In either case it is fed to the gun by a separate motor system.

The system is eminently suitable for an armed helicopter or 'gunship'. In the 20 mm M61 Vulcan version it is used as an anti-aircraft weapon as well as an aircraft gun. One extremely useful feature of the design is that misfires are ejected through the system and ejected with the empty cases. No stoppage of fire is involved. However a hangfire will be ejected like a misfire and could cause serious damage.

The Chain Gun feed mechanism is shown in Fig 12.18. As can be seen, this is a simple method of managing the de-linking, firing, extracting and ejecting processes with the rounds being carefully controlled at each stage.

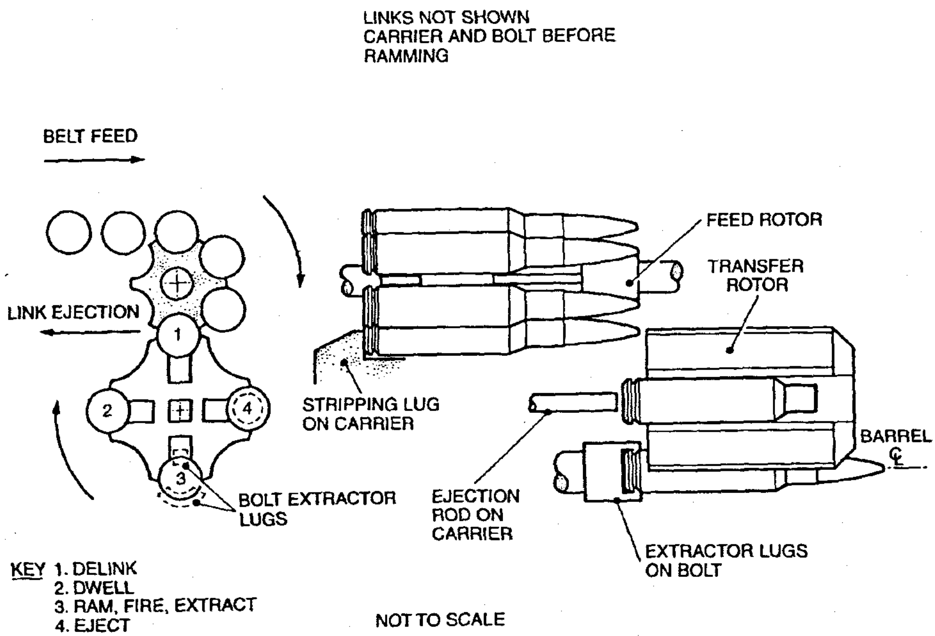


Fig 12.18 Chain Gun Feed Mechanism.

The Function of Loading the Round in the Chamber

Feed mechanisms position the round ready for loading into the chamber and always in line with the axis of the bore. Then, a straight ramming effort to the

base of the case, will cause the nose of the bullet to lead into the chamber where it aligns itself, when loading is completed. This ramming action is, with few exceptions, achieved by the forward stroke of the breech block or bolt, the cartridge having moved into the breech block path during the latter's rearward travel.

The amount that the cartridge moves into the path of the breech block must be limited to prevent any interference from the following one, or a chance of a double feed. For this purpose, metal horns are sometimes provided on the surface of the breech block to engage the base of the cartridge. The cartridge then slides into position of the face of the breech as its angle of feed into the chamber is brought parallel to the axis of the bore by its continued movement into the chamber.

In the few examples where the breech block is not used as a rammer, the reason generally is that the breech block is not of a reciprocating type and does not therefore move sufficiently to act as a rammer. The USA M73 tank machine gun is an example. In these cases, an actuating lever is operated off some moving part and moves backwards and forwards along the line of the axis of the barrel behind the chamber. The lever collects the cartridge in the same way as a reciprocating breech block, working off the gun cycle and ramming the cartridge when the breech is open.

Holding Open Devices

The purpose of a holding open device is to retain the operating mechanism in the 'breech open' position when the feed system requires replenishment. This has two advantages. Firstly the position of the breech mechanism indicates to the firer that his magazine is empty. In those weapons where no holding open device is fitted, the weapon will cease firing with the bolt forward. The firer will apply his first immediate action and re-cock the gun. It is very possible in battle that he will not observe that a case has not been ejected and he will proceed to aim and squeeze his trigger once more without effect. He will then, after this delay, investigate the ammunition position. Secondly, having the action to the rear expedites re-loading. Since this device is an indication of the state of the feed system, it must be operated by it. In its simplest form the feed system provides the holding open device in the form of the magazine platform or follower. The front face of the bolt will exert pressure on the holding open device. Therefore it will be necessary either to press a specially provided release for the hold open device, or to pull back the bolt and so release the pressure, enabling the holding open device to return to its non-operative position and allow the bolt to go forward. Rarely, as in the EM2, replacing a loaded magazine in the weapon will allow the action to go forward and chamber a round automatically. This obviously reduces the time and effort required to resume firing.

In an automatic weapon firing from the open breech position, the breech block must be arrested by the holding open device before the bent meets the sear on the forward movement. Removal of the magazine and replacement by a loaded one, will then allow the working parts to be held to the rear by the trigger mechanism as soon as the pressure on the holding open devices is released. Holding open devices are met infrequently in belt fed guns because the mechanism does not readily lend itself to the incorporation of such a device and also because the element of speed in changing the ammunition supply is not as important where a belt supply is used. There are three basic methods by which the holding open device may control the loading cycle of a weapon:

- A projection on the rear end of the magazine platform obstructs the breech block or bolt.

- A retaining device which operates indirectly by the magazine platform and holds up either the breech block or some other reciprocating part, such as the piston extension in a gas operated weapon.

- A controlling device operated by the feed system which controls the firing mechanism, preventing the loading cycle of the reciprocating parts by the trigger sear.

Holding Open by the Magazine Platform

The projection on the magazine platform is the simplest holding open device and is found in most rifles and LMGs fitted with magazines. The projection rises after the breech block has been retracted and intercepts it at the beginning of its forward movement. If this system is employed, the magazine platform must be robust, particularly in the case of automatic weapons. The .303in BREN LMG employed this method by allowing the feed horns on the breech block to foul the magazine platform. When the magazine is removed, the breech block and piston assembly move forward a short distance until the trigger sear engages the bent on the piston extension.

Holding Open by Interceptor

It is often convenient to use connecting levers between the platform and the actual item that stops the breech/bolt from going forwards. The use of a light platform forces this system on the designer; it has the advantage that a stout interceptor can be fitted in the most suitable location and be combined with a simple magazine platform. Self-loading pistols are fitted with this system because the magazines are generally of light construction. An external catch, by which the retainer can be released, is often found. On some gas operated weapons it will be found that the retaining device engages the piston extension. This method is robust and also logical, because the piston extension carries the breech block and is usually connected with the return spring.

Holding Open by Trigger Mechanism Control

The holding open method of control via the trigger mechanism is more complicated because the trigger assembly already caters for fire control and applied safety. An example of the system does exist, although it is not frequently encountered. The German 20mm Flak 39 HMG included a connection between the magazine platform and the trigger, so that, when the last round was fired, the rising platform disconnected the sear from the trigger.

Summary of Holding Open Devices

Where automatic weapons are to be used at short range in close contact with an enemy, a 'holding open' device must be incorporated to save valuable time on which a firer's life may depend. By indicating that the last round has been fired and ensuring the rapid replacement of the feed system, firing can continue with minimum delay. Holding open devices that do not positively indicate to the firer that the stoppage is caused by an empty feed system do not achieve their object. This device is not so important in automatic guns using a large capacity type of feed system, such as a belt, where the time element is not vital.

13. Trigger and Firing Mechanisms

Definitions

A firing mechanism is the means by which energy is supplied to the cap in the cartridge to initiate it. A trigger mechanism is the mechanism by which the firing mechanism is controlled.

General

In small arms, the firing mechanism will almost invariably be of the percussion type, mechanically operated. Electric primers have practical drawbacks in the field and, in the large quantities in which small arms ammunition is produced, they are more expensive. This is not to say that future small arms might not benefit from electronic and electrical initiation. At present the electric primer either of the bridge wire type, or using a conducting cap composition, is rarely embodied in cartridges of rifle calibre. They are, however, used extensively in 20 mm and 30 mm guns. When a percussion cap is employed in a small arms round, it is necessary for the firing mechanism to deliver an impulsive blow which will supply enough energy to initiate the cap and so fire the cartridge. The amount of energy required is not large. For example the 7.62mm NATO round functions on about 0.4J of energy.

It is usual to employ the term 'striker' when the energy supplied comes either from a spring associated permanently with the striker, or when utilizing the kinetic energy of some mass to which the striker is attached; eg, the piston post of a gas operated LMG, or the bolt of a SMG which has a fixed striker.

When the part that contacts the cap obtains its energy from a separate source, it is referred to as a 'firing pin'. For example, where the firing mechanism consists of a spring operated hammer, that hammer drives forward a 'firing pin'. This terminology is equally applicable to electrical firing.

Firing Pins

Firing pins can be free floating or spring retracted. Free floating firing pins must be designed with some care, otherwise there is a possibility that sufficiently large inertia forces can be generated when the weapon is swung or dropped, to fire the cap. Even if immediate firing is not produced, repeated

light taps of a free floating firing pin may eventually fire the cap. This occurred with early versions of the AR-15 rifle.

Other aspects of firing pins and strikers worthy of consideration are:

- Excessive protrusion will produce pierced caps.
- Excessive striker energy will produce pierced caps.
- A sharply pointed firing pin will produce pierced caps.
- The firing pin/striker must remain in contact with the cap and must be adequately supported as the chamber pressure rises, to prevent the cap perforating and allowing high pressure gas out into the firing pin hole in the bolt.

With a firing pin that passes through the breech block, the question of tempering becomes important. If it is too brittle, it can break, and leave a portion permanently projecting to act as a fixed firing pin, with the result that the round can be fired before the bolt is fully closed. If it is too soft, it will bend and cannot be withdrawn in to the bolt.

Terminology

There are certain terms that are used with trigger and firing mechanisms and these are defined below:

- **Bent.** A recess in some part of the firing mechanism by which the forward movement of the striker may be held up.
- **Sear.** A component of the trigger mechanism that engages in the bent. It is controlled by the trigger. When it is removed from the bent, the latter can move forward and firing begins. When it is engaged in the bent, firing ceases.
- **Cocking.** The preparation of the firing mechanism for firing. It usually involves the storing of energy in a spring and the engagement of the sear in the bent.
- **Lock Time.** This is the time that elapses between operation of the trigger and cap initiation. It is largely a function of whether a 'closed' or 'open' breech system is used.

Open Breech/Bolt Systems

When the gun is ready to fire, the breech block or bolt is held in the open or

rear position. The return spring is under compression and the next round to be fired is still positioned in the conveyor. Operation of the trigger releases the bolt which goes forward, collects a round from the conveyor, chambers it and then supports that round in the chamber. According to the system of operation, the round is fired automatically as soon as the support is complete. A considerable time passes between the firer pressing his trigger and the cap being struck, which in a GPMG will be of the order of 25ms.

Release of the trigger causes a re-engagement of the sear in the bent and the breech block is again held up to the rear, leaving the chamber open. This system has two obvious advantages:

- A round is never left in the chamber with the risk of 'cooking off' which is present when the chamber is hot after prolonged firing.
- The firer does not have to re-cock a heavy breech block against the strength of the return spring whenever he requires to clear the chamber.

There are some disadvantages produced by the movement of the bolt during the lock time. These are:

- The change of the centre of gravity of the gun caused by the forward movement of the bolt and, in some cases, the barrel as well.
- The reaction in the direction of recoil of the powerful return spring as the bolt goes forward.
- The vibrations set up in the body and barrel by the bolt locking, or otherwise supporting the case, directly before firing occurs.

The firer is unable to maintain his aim during the events described above. This is further prejudiced by the heavy trigger pull required to disengage the sear from the bent whilst the full force of the compressed return spring is thrusting the mating surfaces together.

The 'open breech' system is usually used on fully automatic weapons where the spread of shot is used to produce a beaten zone and there is no requirement for single shot accuracy. Some sub-machine guns and light machine guns fire single shot, but as a generalisation open breech systems will not provide as accurate single shot fire as that from closed breech systems.

Closed Breech/Bolt Systems

Here the breech or bolt is closed during the 'ready' period with a round in the chamber. When the trigger is operated the only parts that have to move are the

striker and spring, or the hammer and firing pin, according to the design of the firing mechanism. Since these parts have a very small inertia, the response is very speedy and the lock time is very short. There are no significant vibrations or changes of centre of gravity and so the system is ideal where single shot accuracy is required. From this it follows that the closed breech system is employed in rifles and pistols where accuracy and quick response are the primary requisites. The actual lock time in a closed breech system is dependent upon the mechanical details, being as low as 1.5ms in a Martini type .22in target rifle and as high as some 5.5ms in a well designed 7.62mm SL rifle using a hammer and firing pin. This system has the disadvantages that:

- The propellant is very subject to heating whilst in the chamber and so the ballistics will vary according to the length of the ready period.
- The chamber pressure will vary with propellant temperature and the resultant difference in force produced will affect the vibration pattern of the barrel.
- In a very hot barrel, the round can cook off in a short while although this degree of heat is not likely to be realised in a SL rifle.

Cook Off

The burning propellant heats the barrel and chamber of any weapon. The amount of heat can be considerable when firing at a high cyclic rate. The chamber eventually reaches an equilibrium temperature which, in a GPMG, can be about 600°C. A round exposed to this temperature for as little as 5s can produce spontaneous ignition of the propellant resulting in firing of the bullet in an unintended direction with possibly hazardous results.

A misfired round may cook off and the case burst whilst the firer is extracting it from the chamber as the first immediate action. If the ammunition is fuzed, the main high explosive filling may ignite and then detonate. This could injure the firer severely and even destroy the gun.

The actual time taken for cook off for a given chamber wall temperature depends mainly upon:

- The chamber wall thickness.
- The chamber design eg, fluted.
- The type of propellant.
- The cartridge case material.

- The cartridge case thickness.
- The air space and cooling effects around the barrel and body.

Trigger Mechanisms

The trigger mechanism consists of the mechanical linkage, or the electric device, which controls the firing mechanism. It may be operated by hand or from a remote position using either mechanical or electrical linkage. The requirement for remote control can exist in an armoured fighting vehicle, but is rare otherwise.

The function of a trigger mechanism is to initiate the train of events that cause the firing mechanism to operate and fire a cartridge. Its mechanism, in a self-loading weapon, may ensure that only one round can be fired each time it is operated. In a weapon that can fire fully automatic, it stops the weapon firing when desired by controlling the firing mechanism and ensuring that the working parts are brought to rest in the correct part of their cycle. Fire can then be reopened by a further operation of the trigger by the firer as required.

Other Uses for the Trigger Mechanism

In a pistol or revolver, the initial manual operation of the trigger may be used to cock the hammer and store energy in the hammer mainspring. Further operation of the trigger lever then releases the hammer.

Safety devices, both applied and grip, may make use of the trigger mechanism so that it cannot be operated or cause the firing mechanism to be operated. These safety devices are, however, not a fundamental part of the trigger mechanism and often operate direct onto the firing mechanism, where ideally they positively lock the striker or firing pin. This is more satisfactory and eliminates the possibility of a failure of the safety device caused by the firing mechanism operating although the trigger is locked. This could occur as the result of a breakage or mechanical failure in the mechanisms from the trigger to the striker.

The selection of the type of fire required – single shot or automatic – may be both controlled by use of the trigger lever or mechanism. Again this is subsidiary to the primary function of the trigger but may enable the designer to make a simpler mechanism by combining it with the trigger. This selection is sometimes made by enabling the trigger to be operated in two different ways to select the type of fire required, or the control of the selection of the type of fire may be operated separately from the trigger, but operate through the medium of the trigger mechanism.

These other functions achieved in the trigger mechanism and elsewhere will be

dealt with in detail later in this chapter, but it is necessary to appreciate their possible inclusion in the trigger mechanisms before it is dealt with in detail.

Trigger Operation

The train of events in trigger mechanisms is initiated by the manual operation of some form of trigger control. In small arms this usually takes the conventional form of any simple lever in a convenient position either on the weapon, its mounting or in the fighting compartment, that can be pushed, pulled or operated by the foot. Where it is remote from the gun it may operate the trigger mechanism through the medium of a rod linkage, bowden cable, lanyard or an electric circuit and, in the case of the latter, can be controlled by an electric switch or button. There are examples in common use of all these types of trigger operation. They normally fall into categories according to the type and role of a particular weapon. The simplest way to study trigger and firing mechanisms is by considering both of their applications to each classification of weapon in turn.

Striker or Firing Pin Design

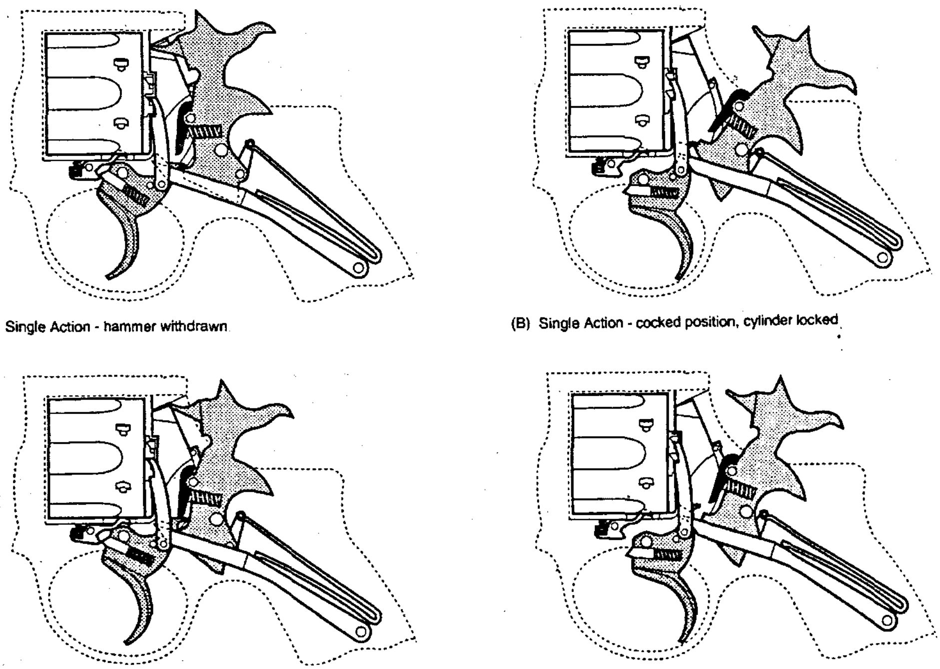
A blunt nosed striker usually gives a better transfer of energy and crushing effect to the cap, with more positive and efficient ignition of the cap composition. The energy imparted to the striker will be affected by its mass, that of the working parts that operate it, and their source of energy. A firing mechanism may have its own method of storing and applying energy, or it may make use of some operating part of the gun which has energy to spare. In both pistols and rifles, the striker is generally operated by its own mechanism or source of energy and in automatic weapons more commonly by making use of some working part of the gun operating system.

Revolver and Pistol Mechanisms

Actions may be either single or double. In a single action pistol the firing mechanisms is cocked by hand, although subsequent firing with a self-loading pistol will cock the firing mechanism as a part of the operating cycle. In a double action pistol the firing mechanism may be cocked also by the initial operation of the trigger mechanism. In the case of a self-loading pistol of this type, subsequent firing causes the firing mechanism to be cocked as a part of the operating cycle. The additional advantage is, in the case of a misfire, a second application of the trigger will cock and operate the firing mechanism again, giving a second chance of the round being fired, a considerable advantage in a close quarter weapon. An added advantage is that a loaded pistol may be carried with the firing mechanism uncocked and yet be immediately available for action by the application of the trigger. However with a revolver, a second pull of the trigger will index and present a new round for firing in a very much shorter time than a stoppage can be cleared in a pistol.

Revolvers

Fig 13.1 illustrates the trigger mechanism of a typical revolver.



(A) Single Action - hammer withdrawn

(B) Single Action - cocked position, cylinder locked

(C) Double Action - cocking hammer rotating cylinder

(D) Double Action - hammer cocked

Fig 13.1 Trigger Mechanism, Revolver .38in.

Self Loading Pistols

Self-loading pistols are generally too light to be controlled in automatic fire and their cyclic rate is so high that their normal magazine capacity would be insufficient. To ensure only one shot is fired for each application of the trigger lever, self-loading pistols incorporate a disconnecter in the trigger mechanism which is functioned by the movement of the working parts as each shot is fired. This ensures that the sear will re-engage and arrest the firing mechanism in the cocked position after each shot is fired, even though the trigger remains squeezed.

The .45in Colt pistol, shown in Fig 13.2, illustrates the operation of a disconnecter. It also includes both a grip and applied safety in its trigger and firing mechanism. It has been mentioned already that these additional functions are sometimes incorporated in the mechanism of a trigger for design simplicity.

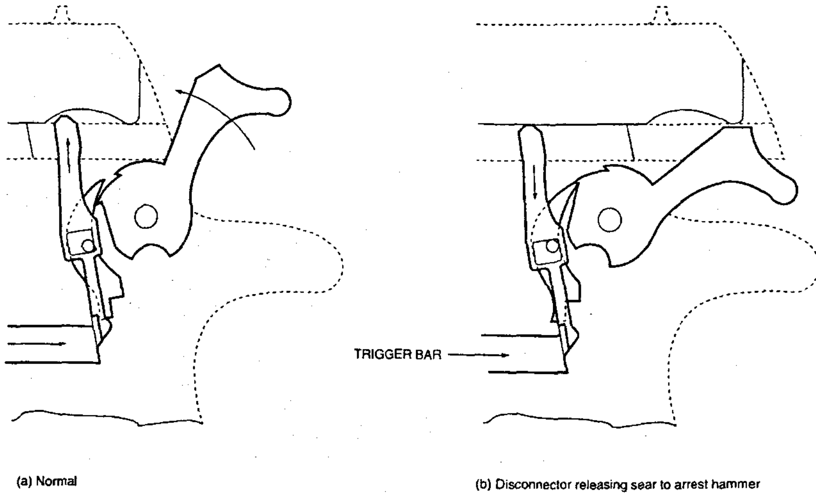


Fig 13.2 Disconnector, Colt .45in SL Pistol.

The disconnecter, as in all self-loading pistols, has two functions. Firstly, it ensures that the pistol can fire only one round for each application of the trigger and secondly, it ensures that the mechanism cannot be fired unless the breech is locked or the working parts are in the correct position, thus achieving mechanical safety.

In most self-loading pistols, using a hammer mechanism, this mechanical safety is practically achieved by the hammer and firing pin being unable to make contact, because the slide obstructs the path of the hammer unless the working parts have completed their travel forwards.

The disconnecter lever in the example shown is controlled by the position of the breech block or slide. In the breech locked position, the lever rises under the influence of a spring into a recess under the bolt. When it is in this position, operation of the trigger lever will cause the flange at the bottom of the disconnecter lever to rotate the sear, releasing the hammer and firing a cartridge.

As the slide and barrel recoil, the disconnecter is forced downwards, as the recess on the underside of the bolt moves rearward. This causes the flanges of the disconnecter to be displaced from the front of the sear, enabling the sear under the pressure of its spring to re-engage in the hammer bent, when the hammer is cocked by the rearward motion of the working parts. Now the flanges of the disconnecter are under the sear which it cannot now operate. But when the trigger lever is released it enables the disconnecter spring to push the disconnecter forward in front of the sear again. If the working parts are forward, the disconnecter lever can rise into its recess in the slide, bringing its flanges once more between the trigger bar and sear, which it can then

operate when the trigger lever is pulled again.

The grip safety in the Colt .45in pistol, illustrated in Fig 13.3, controls the operation of the trigger lever. When the safety lever is not pressed by the grip of the hand, the nose of its operating rod is against the end of the trigger bar so that the trigger cannot be operated. When the safety is pressed by the grip of the hand the operating lever is rotated out of line with the trigger bar, which is then free to operate. This safety depends on spring pressure to cause it to function in the safe position. The object of this safety is to ensure that the trigger cannot be accidentally operated when the pistol is not being held firmly in the hand, ready for firing.

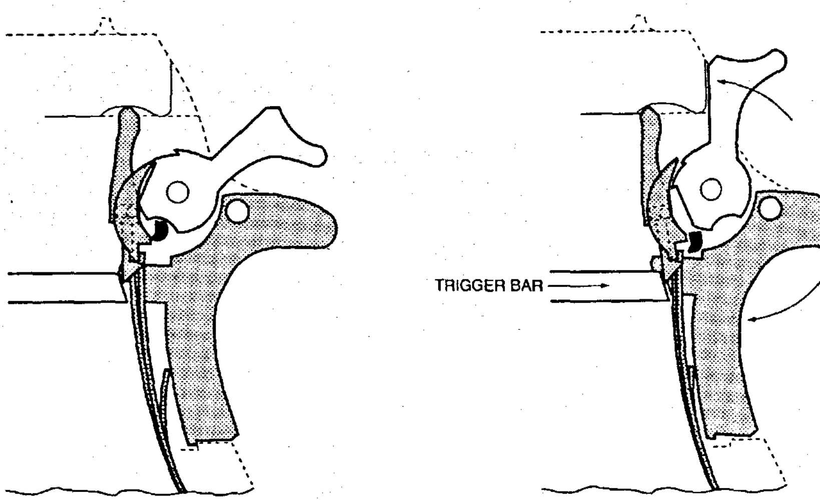


Fig 13.3 Grip Safety, Colt .45in SL Pistol.

A further safety device is incorporated in the firing mechanism of this pistol in the form of an additional bent on the hammer; it is in the form of a definite recess as opposed to the normal step. This achieves the safety position known as 'half cock'. When the hammer is in the half cocked position, the sear cannot jump out of the bent recess until the hammer is definitely withdrawn to clear the lip of the sear. This enables a loaded pistol to be carried with the hammer well clear of the striker and only a short retraction of the hammer is required to engage full cock. Additionally, should the hammer bent in the fully cocked position, jump the sear when the trigger has not been operated, the half cock bent will engage the lip of the sear, positively arresting the hammer and preventing it from firing a round.

The main elements of the mechanism in this pistol are simple and clearly shown in the diagrams. The firing mechanism consists of a firing pin and spring which withdraws it to its normal position after it has been struck by the

hammer and operated the cap, and the hammer with its two bents and its spring to store energy and operate it. Its comb is milled to provide a grip for the thumb to cock it. The trigger mechanism consists of a conventional operating lever which operates the sear through the medium of a bar, a spring being provided to return both the sear and the trigger lever to their normal position after operation.

Sub Machine Guns

The SMG is designed to produce a large volume of fire, usually at a high cyclic rate. At the same time the weapon has to be easy to handle, control and direct. These requirements lead to a short weapon with a barrel restricted to 8-10in and consequently with limited accuracy. Where the gun is required to fire at full automatic only, the trigger and firing mechanism may be extremely simple. This is shown in the USA SMG the .45in calibre M3 as illustrated in Fig 13.4.

The firing mechanism is a fixed striker on the front face of the bolt and the means of controlling it is the trigger, trigger bar and sear. The sear rotates about the sear pin and normally the trigger spring will hold the sear up by exerting a forward tension on the trigger bar. When the trigger is squeezed, it rotates about the trigger pin and pushes the trigger bar forward. The sear is then depressed and disengaged from the bent and the bolt is driven forward by the compressed return spring. When the trigger is released, the spring pulls the trigger bar rearwards and the sear is rotated into the path of the bent. This mechanism is simple, reliable and cheap.

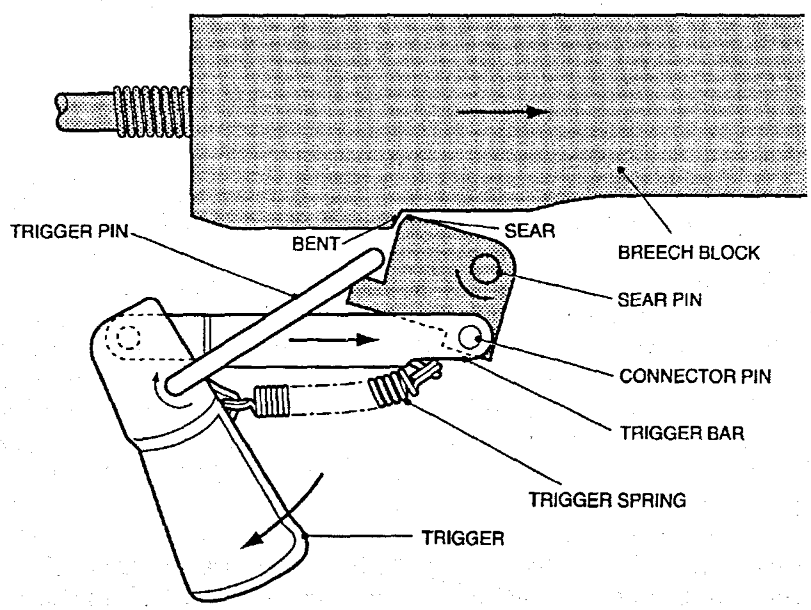


Fig 13.4 Trigger and Firing Mechanism, USA M3 SMG

When the SMG is required to produce single shots as well as bursts of fire, the mechanism becomes more complicated because it is generally necessary to introduce a disconnecter, as in the British L2A3 SMG shown in Fig 13.5.

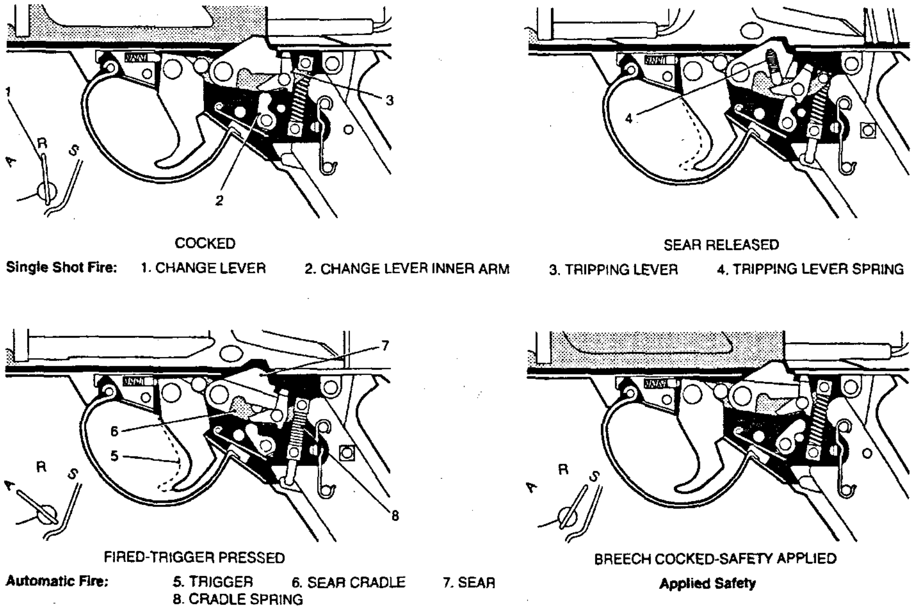


Fig 13.5 Trigger and Firing Mechanism, 9 mm L2A3 SMG

The sear cradle carries the spring loaded sear, which is capable of independent rotation about its own axis pin and a tripping lever which can also rotate under the force of its own spring.

The gun fires from the open breech position and, when it is cocked, the bent on the bolt is engaged in the sear. When the trigger is pressed, the sear cradle is rotated about its own axis, carrying the sear down with it and compressing the sear cradle spring.

At full automatic, the gun continues to fire until either the trigger is released or the ammunition is expended. When single shot is set on the change lever, the inner arm is positioned under the toe of the tripping lever. When the cradle rotates carrying the sear with it, the inner arm of the change lever rotates the tripping lever which moves clear of the sear. The sear rises and the bolt is caught and held back after firing one round.

The SMG as a weapon is particularly prone to accidental discharge. The STEN SMG for example, could be dropped from a vehicle onto its butt and the inertia of the heavy bolt would cause it to set back sufficiently to pick up a round from the magazine, feed it and, after chambering, to fire it.

Modern weapons of this kind incorporate devices to ensure that accidental discharge is prevented. A typical example of this is the Israeli SMG the UZI. This incorporates a grip safety that must be squeezed before the bolt can be moved at all. Once the weapon is cocked it is impossible to fire it unless the grip safety is correctly squeezed. The mechanism by which this operates is shown in Fig 13.6.

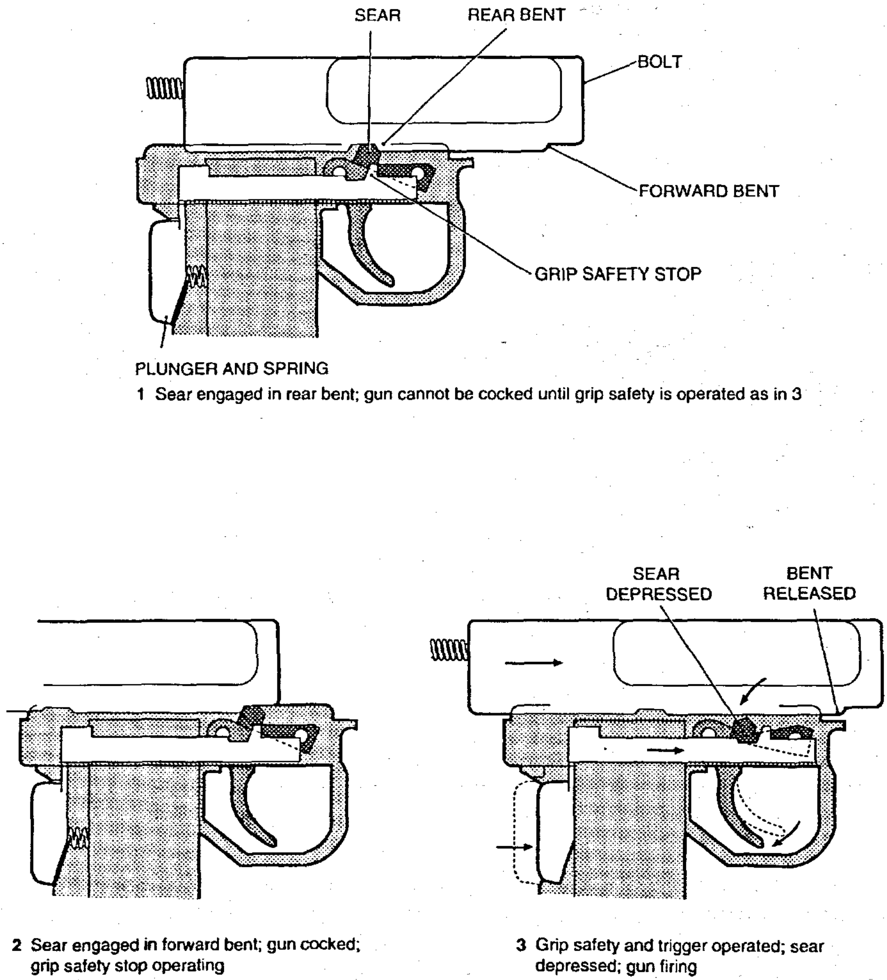


Fig 13.6 Grip Safety, UZI SMG

Rifles

The rifle is the soldier's personal weapon and its first requirement is a high degree of accuracy. To achieve this the trigger mechanism must be carefully designed. It is essential that, once the sights have been lined up on the target,

there should be the minimum of delay before the cap is initiated and the action of the trigger must be both light and smooth.

This leads to a closed breech firing and some device to enable the firer to take up the overlap between sear and bent, which is required when the weapon is being carried cocked, and by its feel indicate that only a slight further movement is required to release the bent. To achieve this effect the 'double pull' trigger mechanism has been in use in service rifles for many years.

Manually Operated Rifles

In the No. 4 rifle illustrated in Fig. 13.7, there is an initial overlap of the sear and bent of between 0.76mm and 1.0mm. This is required so that the weapon can be carried cocked, without danger of the bent being knocked off the sear due to the weapon being dropped or otherwise mishandled. The initial operation of the trigger causes the nose of the sear to move down the face of the bent to give an overlap reduced to 0.25mm. This initial movement is known as the "first pull" and the firer takes this pull before he finalises his sight picture. Once he has critically aligned his sights, only a short light squeeze is required to fire the round: this is the second pull. The design must also allow for first pull sear recovery if the second pull is not taken. This is achieved by carefully selected angles on the bent and by an extremely good surface finish. Fig 13.7 shows the double pull trigger arrangement for the No. 4 rifle.

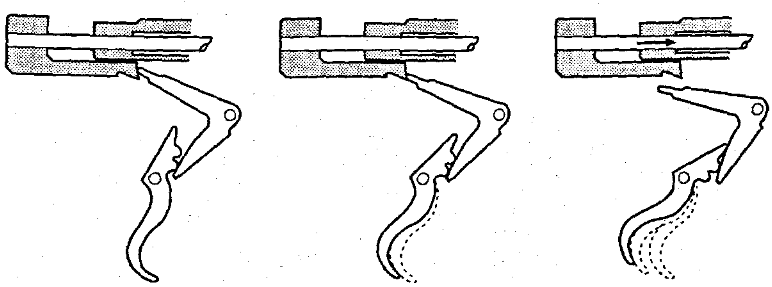


Fig 13.7 Double Pull Trigger, No. 4 rifle.

These two pulls are achieved by the two ribs on the trigger operating lever. The lower rib operates the sear for the initial pull of 13 to 18N. This low pull comes from the mechanical advantage achieved. When the higher rib comes into contact with the sear lever, the mechanical advantage is reduced and the pull goes up to 22 to 27N. The firer knows at once from the different feel that the first pressure is completed and taking a further pressure will produce an immediate disengagement of the sear from the bent. This type of double pull trigger can be found on the L96A1 sniper rifle. The same effect as a double pull trigger is achieved in some sporting rifles by having two triggers. The first trigger operates the initial movement of the sear, leaving it in a very sensitive

position, so that slight pressure on the second trigger will cause the weapon to fire. By this method the second trigger can be made into a hair trigger by the operation of the first.

The firing mechanism in the case of a manually operated service rifle is normally cocked by the operation of the bolt. With the Lee-Enfield action, when the bolt is pushed forward to load a fresh round, the bent in the cocking piece is held up by the sear lever, causing the striker spring to be compressed between the collar of the striker and the rear inside face of the bolt. With the Mauser action the firing mechanism is cocked when the bolt is opened.

Self Loading Rifles

There is a distinct similarity between the devices used to produce single shots in a SL rifle and those used in a SL pistol. Almost invariably the firing mechanism consists of a spring loaded hammer and firing pin and the single shot device will consist of a disconnecter or a double bent device system. Fig 13.8 shows the arrangement used for the 7.62mm SLR.

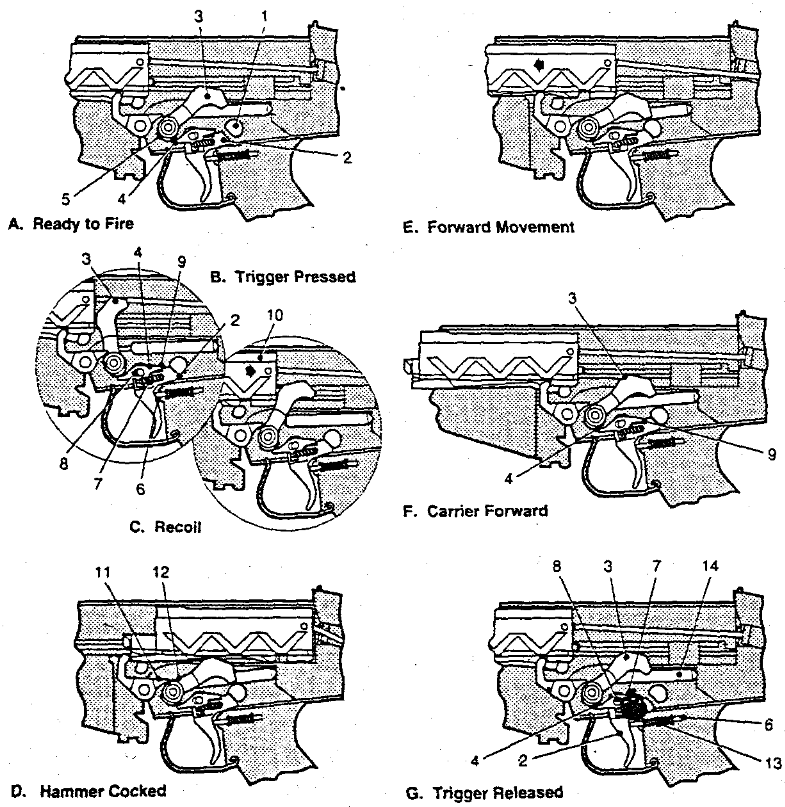


Fig 13.8 Trigger and Firing Mechanism for the 7.62mm Rifle, L1A1 SLR

The British rifle, the L1A1, was derived directly from the Belgian FN rifle, the FAL, and the two mechanisms differ only in that the British rifle is restricted to SL fire, whilst the Belgian weapon can produce automatic fire as well.

Firing

When the safety catch (1) is set to repeat (R), the flat surface of the spindle is directly opposite the tail of the trigger (2). The hammer (3) is held by the nose of the trigger sear (4) engaging the lower bent (5) of the hammer. The rifle is ready to fire (Fig. 13.8a).

Pressure on the trigger (Fig 13.8B) causes the rear of the trigger (2) to rise and depresses the trigger plunger (6). It also forces upward the tail of the sear (4), rotating the sear and disengaging its nose from the lower bent of the hammer. The sear spring (7) immediately pushes the sear forward along its elongated axis (8) and, at the same time, the tail of the sear slips into the step (9) on top of the trigger; the nose of the sear frictions on the hub of the hammer. The hammer (3) rotates forward firing the round, recoil takes place (Fig 13.8C) and the hammer is rotated rearward by the carrier (10). As the hammer reaches the limit of rearward rotation (Fig 13.8D) the safety sear (11) engages the upper bent (12) of the hammer and the trigger sear is positioned behind the lower bent but not in contact; the weight of the cocked hammer is borne by the safety sear.

Forward movement of the carrier now takes place (Fig 13.8E) and, at the end of it, the safety sear is tripped and disengaged from the hammer (Fig 13.8F). The hammer (3) rotates slightly forward and is held by the nose of the trigger sear (4) engaging the lower bent of the hammer. The nose of the trigger sear is now at its highest position with the tail fully engaged in the step (9) of the trigger. The backward thrust on the sear is taken up by the step of the trigger. During this action the trigger is still pressed.

To fire another round, the trigger (2) must be released and pressed again. As it is released (Fig 13.8G) it is rotated forward under the influence of its plunger (6) and spring (13), but the trigger sear (4) is prevented from rotating as its nose is in engagement with the bent on the hammer. The step moves downward away from the rear of the trigger sear and the compressed hammer spring (14) rotates the hammer (3) slightly forward, forcing the trigger sear rearward along its elongated axis (8), overcoming the sear spring (7). The tail of the trigger sear is now above the top rear of the trigger ready to fire another round.

Another form of disconnecter is used in the Russian Simonov SKS rifle, shown in fig 13.9. When the trigger is squeezed, the trigger bar pushes the spring loaded sear forward and clear of the hammer. Provided the bolt is fully forward, the hammer rotates and the round is fired. The bolt moves rearwards and

rotates the hammer. The hammer forces down the disconnecter which in turn pushes down the trigger bar which slips under the spring loaded sear. The sear spring forces it back under the hammer which is then held and cannot move. To fire another round the trigger must be released. The trigger bar comes back and the trigger spring is strong enough to force it up behind the sear again. This action is shown in Fig 13.9a. Unless the bolt is fully forward, the safety sear holds up the hammer.

Automatic Rifles

Each of the methods used for single shot fire can readily be adapted for continuous fire. The double bent system is easily adapted for automatic fire. The spring loaded auxiliary sear holds the hammer back in exactly the same way as SL fire in the double bent AK 47 illustrated, but the closure of the bolt carrier operates a safety sear which pulls the auxiliary sear off the hammer bent.

The L1A1 rifle (see Fig 13.8) requires only a further flat machined on the spindle of the change lever. This will allow the step on the trigger to rise so high that the nose of the sear is depressed sufficiently to be completely clear of the hammer bent. Thus the fire is controlled entirely by the safety sear which releases the hammer every time the carrier goes fully forward. Fig 13.9 shows how automatic fire is achieved in the AK47.

Using this system an SL rifle can readily be converted to full automatic. An example of this is the USA M14 rifle designed for semi-automatic fire only. It was intended to produce an M15 which would have had an automatic capacity but development of this weapon was halted and a simple modification was made to the M14. Every time the cocking handle goes fully forward, it comes in to contact with a linkage which pulls off the auxiliary spring loaded sear and the weapon is fired. Thus the closing of the breech block which completes the locking, fires the gun and maintains the mechanical safety which is further assisted by the fact that the firing pin is shielded from the hammer until locking is completed.

Alternative Open or Closed Breech Firing

Some designs incorporate in their firing and trigger mechanism devices whereby a 'closed' system is employed for single shots and an 'open' system for automatic fire. In the German FG42 automatic rifle, shown in Fig. 13.10 and 13.11, the energy for the striker was provided by the moving parts of the operating mechanism, as in many automatic firing weapons. In this case, the working parts providing the energy consisted of the piston extension and its return springs. As a result of this, it can be seen straight away that the position of the piston extension in relation to the trigger sear determined whether a 'closed' or 'open' firing system was used.

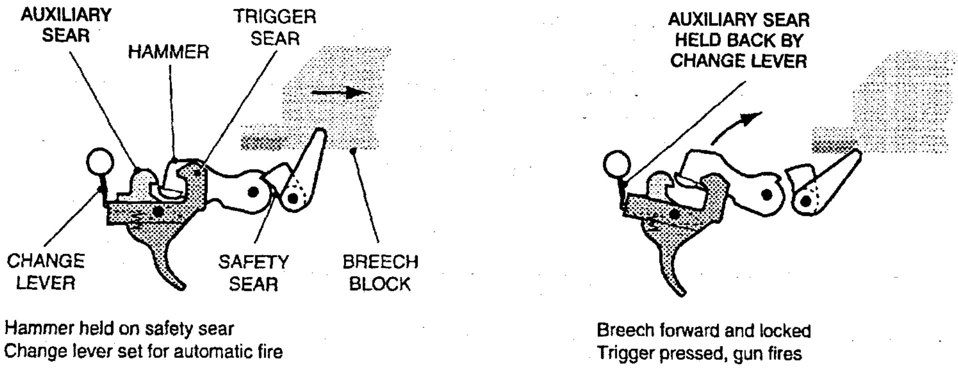


Fig 13.9a Double Bent Auto Fire, AK47 Rifle.

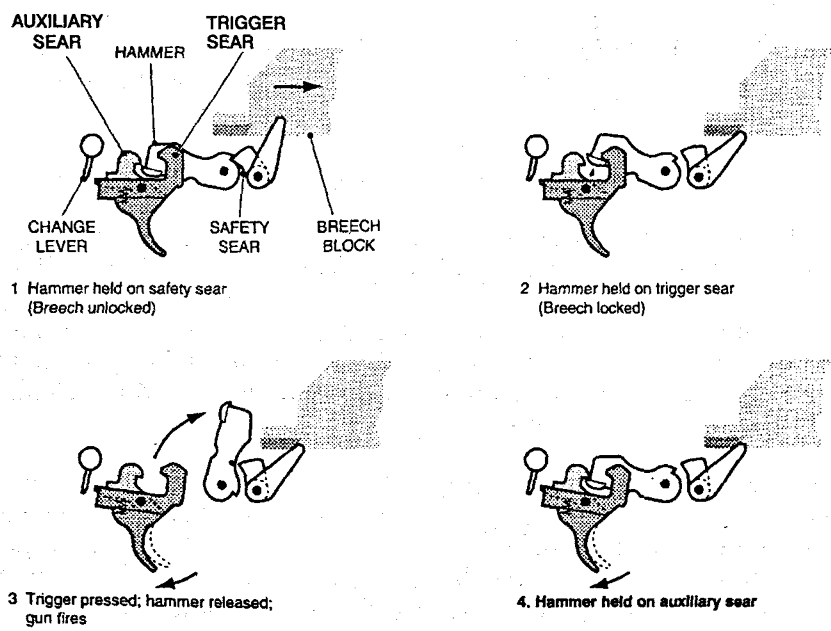


Fig 13.9b Double Bent Single Shot, AK-47 Rifle

To achieve these alternative positions there were two bents on opposite sides of the piston extension. A forward one to arrest it on the sear in its open position for automatic fire and a bent further rearward to arrest it after it had locked the breech but before it had operated the striker, for use with a closed firing system.

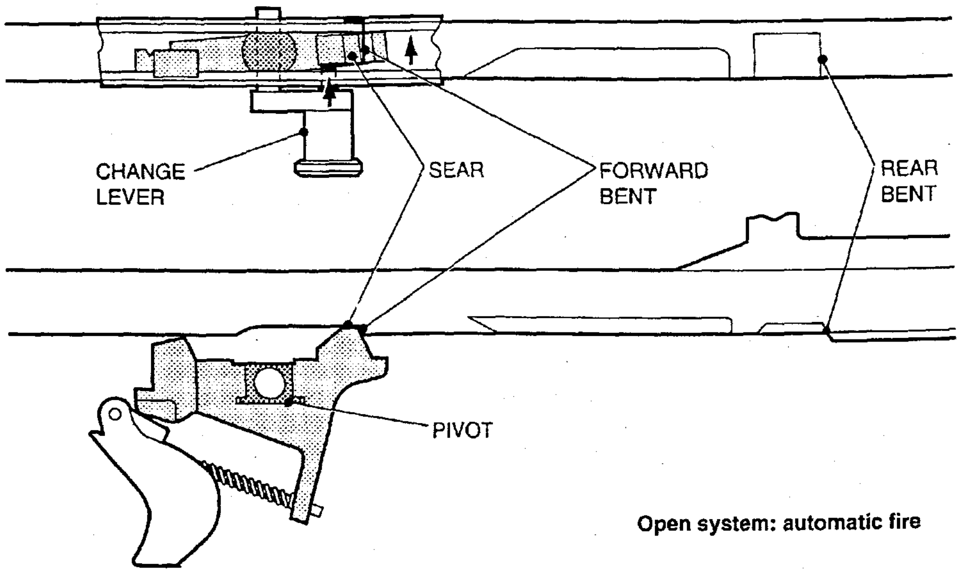


Fig 13.10 Optional Open Breech System, Trigger and Firing Mechanism FG42 rifle.

Although the breech was locked with the working parts nearly completely forward in this 'closed' system, the final operation of the striker still involved the movement of the masses of the piston extension and its return springs. Therefore, although the system had been improved, it was not an ideal closed system such as is found on weapons with self-contained firing mechanisms. These have their simple, comparatively light and short moving mechanisms that cause only slight vibrations.

The trigger mechanism itself in the FG42, was comparatively simple and combined a 'type of fire' selector device. This achieved its function by moving the sear laterally across the body of the weapon to engage the appropriate bent on the piston extension. It included a straightforward disconnecter, which operated at single shot by disconnecting the sear from the trigger lever after each round, thereby ensuring that the next round was fired only after further operation of the trigger. The disconnecter moved in a cam way cut in the underside of the piston extension.

Since the piston extension in the closed system had only a short distance to travel to operate this striker and its return spring was already nearly extended, an auxiliary spring was fitted in the breech block to ensure sufficient energy was provided for the striker. This amplifies the previous remarks that a 'closed' system is more satisfactory with a self-contained firing mechanism.

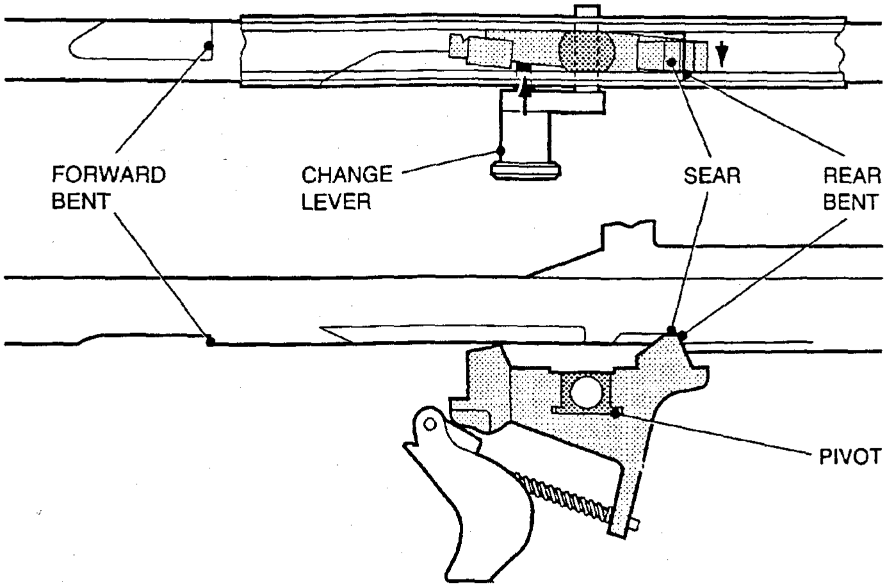


Fig 13.11 Optional Closed Breech System, Trigger and firing Mechanism, FG42 Rifle.

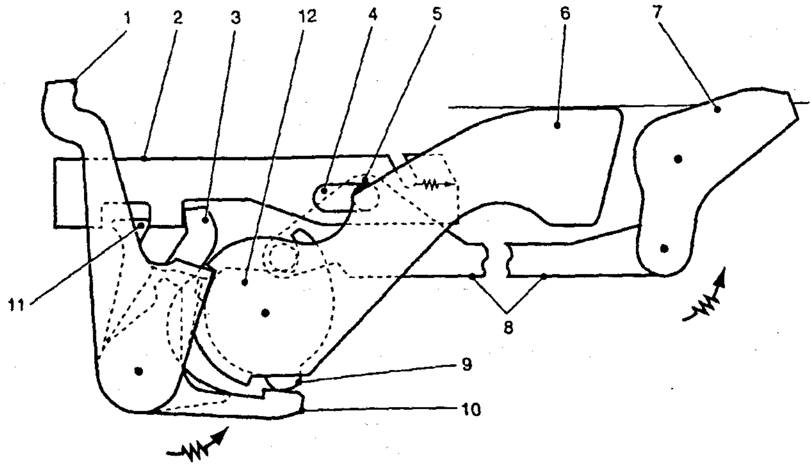
British EWS 4.85mm System

Another weapon to have an open and closed bolt capability was the experimental 4.85mm Enfield Weapon System (EWS) shown in Fig 13.12, but this was never carried through to SA80.

When the change lever is set to (A) auto, the lower lobe on the cam (9) engages the nose of the sear interceptor (10), rotating it, thus causing its tail to disengage the sear, hence control of the sear on the interceptor is withdrawn. At the same time, the upper lobe (12) has engaged the underside of the trigger bar retainer (3), rotating it forward to a point where the nose engages the trigger bar (2) to act as a stop. This action moves the trigger bar (2) forward slightly and reduces the length of the trigger pull.

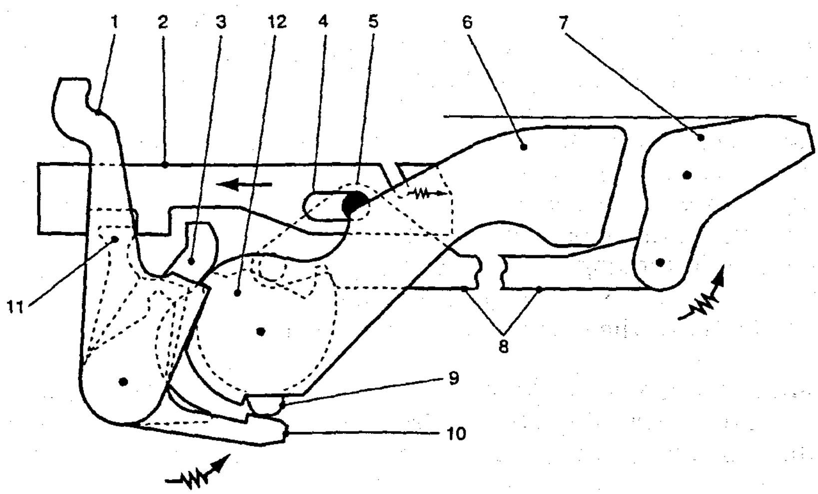
Rotation of the cam also moves the hook at the top of the cam rearwards, allowing the rear sear link (8) to move rewards also and the rear sear (7) to rise under the action of its spring, into the path of the carrier.

The upper pin (5) of the rear sear link (8) engages the rear of the elongated slot (4) in the trigger bar (2) and by this means the rear sear link (8) becomes an extension of the trigger bar (2). Therefore, when the trigger is operated, the action of the mechanism is the same as for the IW on single shot. But in addition, the forward movement of the trigger bar is extended to the rear sear link (8) and the rear sear rotates clear of the underside of the carrier.



1	Safety	7	Rear sear
2	Trigger bar	8	Rear sear link
3	Trigger bar retainer	9	Lower lobe
4	Elongated slot	10	Sear interceptor nose
5	Pin	11	Sear
6	Hammer	12	Upper lobe

Fig 13.12a EWS LSW Change Lever Mechanism Cocked for Auto Fire.



1	Safety	7	Rear sear
2	Trigger bar	8	Rear sear link
3	Trigger bar retainer	9	Lower lobe
4	Elongated slot	10	Sear interceptor nose
5	Pin	11	Sear
6	Hammer	12	Upper lobe

Fig 13.12b EWS LSW Trigger Mechanism Forward Action on Auto.

Relaxation of pressure on the trigger allows the rear sear (7) to rise and arrest the carrier and bolt assembly at the rear of the weapon, thus providing open bolt operation in this automatic mode.

Burst Fire Controls

With weapons of high impulse and low weight, it is almost impossible to maintain an aim when firing at full automatic. In single shot fire there is no problem, because the muzzle rises only a fraction of an inch whilst the bullet is in the bore; this is taken up in the zeroing but, at full automatic fire, the rise is progressively increased after each shot. To prevent wastage of ammunition and to provide time to re-align the weapon, the burst fire control was introduced. When the change lever is correctly set, trigger pressure provides a burst of three rounds only. This is achieved by using two sears, side by side, both of which go down when the trigger is operated. One sear is fully conventional, the other is spring loaded and is allowed to rise every time a ratchet is operated by the recoiling breech carrier. There are three teeth on this escapement mechanism and after the third shot the sear comes fully up and holds the bent of the firing mechanism. When the trigger is released, the other sear, which is slightly shorter, rises and operation of the trigger again drops both sears and a further burst of three rounds is fired. This system has been tried on the USA M16 and is a feature of the FN Carbine Automatique Legere (CAL).

The CAL controller illustrated in Fig 13.13 has the useful feature of returning to the start position each time the trigger is released, thus ensuring a three round burst for each trigger operation regardless of the number of rounds fired in the previous burst.

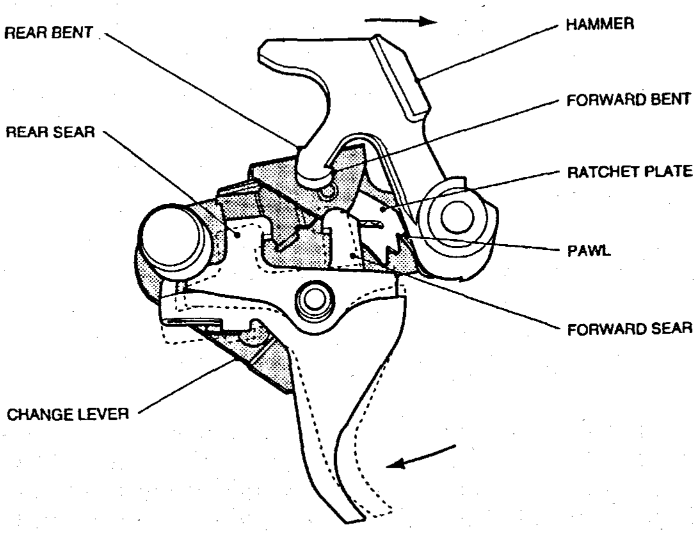


Fig 13.13 Burst Fire Controller, 5.56mm FN CAL

Machine Guns

With the exception of light machine guns and machine carbines, machine guns only have to cater for automatic fire. As a result, their trigger mechanisms only have to start and stop the gun firing; consequently they are simple except where individual designs combine some other function.

The majority of their designs use the effect of the movement of their working parts to provide the energy for operating the firing mechanism, since they use an 'open' firing system to prevent 'cook off'. Any inaccuracy caused by using this system is only effective for the first round of the burst and is considerably nullified by the rigid mounting of the weapon, which in any case does not require single shot accuracy for its role.

A sear operating in conjunction with an 'open' firing system will require a considerable effort to cause it to disengage from the working parts, since their return springs will be under compression. This is a factor that must be borne in mind when designing a remote control trigger mechanism for a gun with an 'open' firing system.

Machine guns having a high cyclic rate of fire often adopt one of two methods for ensuring both positive engagement of the sear and preventing it or the bent from being damaged, due to the energy of the fast moving masses being arrested sharply. Either the sear is buffered, often being progressively pushed up into the face of the bent during this movement, or the sear has a controlled release device ensuring the whole of its face engages with the bent when it is presented.

The normal mechanical and applied safeties have to be incorporated in the mechanisms of machine guns. The gun must be capable of being loaded and yet be safe; either with the breech block locked or, in the case of 'case projection' operation, in the correct position for firing by incorporating a positively controlled striker mechanism before the round is fired.

Fire Selector Devices

On the BREN LMG, the trigger operation above is conventional. But the trigger lever operates the sear through the medium of a tripping lever which can engage two alternative surfaces on the sear to operate it. The change lever controls which of these surfaces is engaged, thereby affecting the type of fire obtained. Fig 13.14 shows the arrangement of the BREN fire selector.

This is an example of a trigger mechanism where the designer has incorporated in it a device for controlling the type of fire. When the 'change lever' is set for "single shot", it allows the tripping lever to rise and engage the higher operating surface of the window in the sear and causes the tripping lever head to rise up into the piston extension path. When the trigger is operated and releases the

sear from the bent, the tripping head will rise into the path of the piston extension on its forward loading movement. The extension will therefore depress the tripping lever as it passes, disengaging the tripping lever from the sear. This will then rise under the influence of its spring to engage the bent in the piston extension on the next cycle, preventing the loading and firing of another round. When the trigger is released the tripping lever will rise and pass the sear operating surface to re-engage and operate it, when the trigger is again squeezed. It can be seen therefore, that this single shot control is no different both in conception and operation from the one shot disconnecter device on self-loading weapons. However it has an additional feature. When the change lever is set to 'automatic' it depresses the tripping lever to engage the sear by a lower operating surface in the window, therefore lowering its tripping head clear of the piston extension path. When the trigger is operated, the sear is not disconnected from it by the action of the tripping head. Thus the working parts are not arrested until the trigger is released by the operator, enabling the firer to start and stop the gun firing and control the length of a burst. This 'control of type of fire' device is simplified by making use of the conventional trigger mechanism and the change lever is conveniently close to the trigger to enable it to be operated by the same hand.

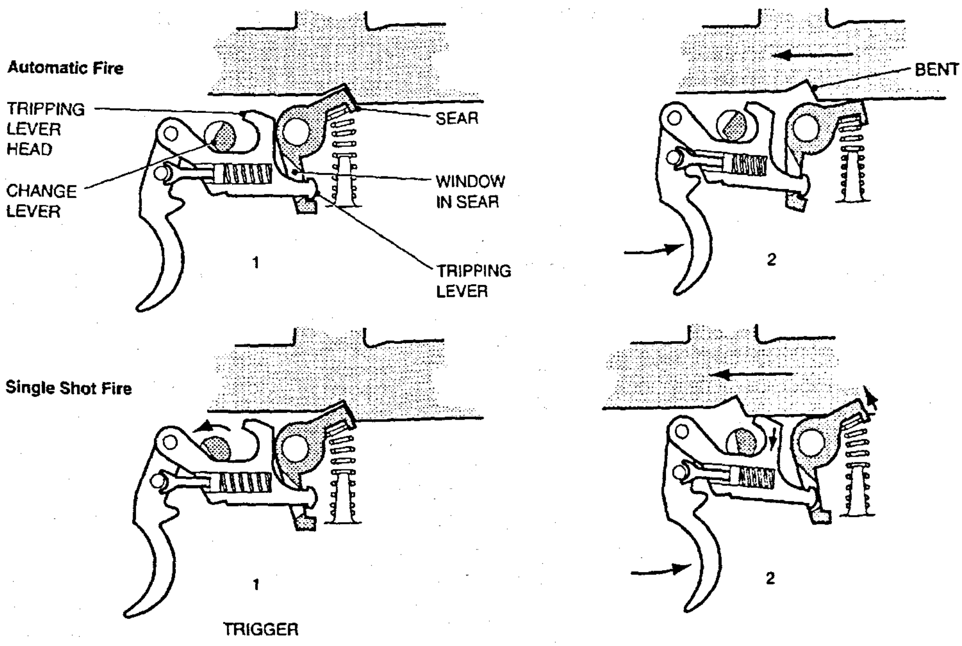


Fig 13.14 Fire Selector, BREN LMG

The Czech Vz 52 and German MG34 achieve the same effect in their trigger mechanisms by a different method. Two trigger operating levers are combined into one trigger; operation of the top part of the trigger achieves a single shot

operation of the sear by employing a disconnecter and operation of the bottom part of the trigger achieves automatic fire by controlling the sear without the disconnecter interfering. Here control of fire is again effected by one hand, in this particular case by the trigger finger.

Controlled Release Sear

In machine guns with a high cyclic rate of fire, the mass of the working parts will have a high velocity. It is advisable to ensure that the full operating face of the sear will engage the bent when it is presented, to prevent damaging or breaking the faces of either.

Medium machine guns and GPMG only cater for automatic fire, and unless some controlled release device is incorporated in their mechanism, the sear will only rise at the speed the firer releases the trigger lever. This will be neither sufficiently fast, nor necessarily at the correct instant to ensure positive engagement of the bent. The degree of over-travel of the bent beyond the sear and the strength of the buffer affect the ease of full surface engagement. The controlled release sear device ensures this positive engagement by controlling the instant and speed at which the sear is released, after the releasing of the trigger lever by the firer. The German MG3 embodies this device and is detailed in Fig 13.15.

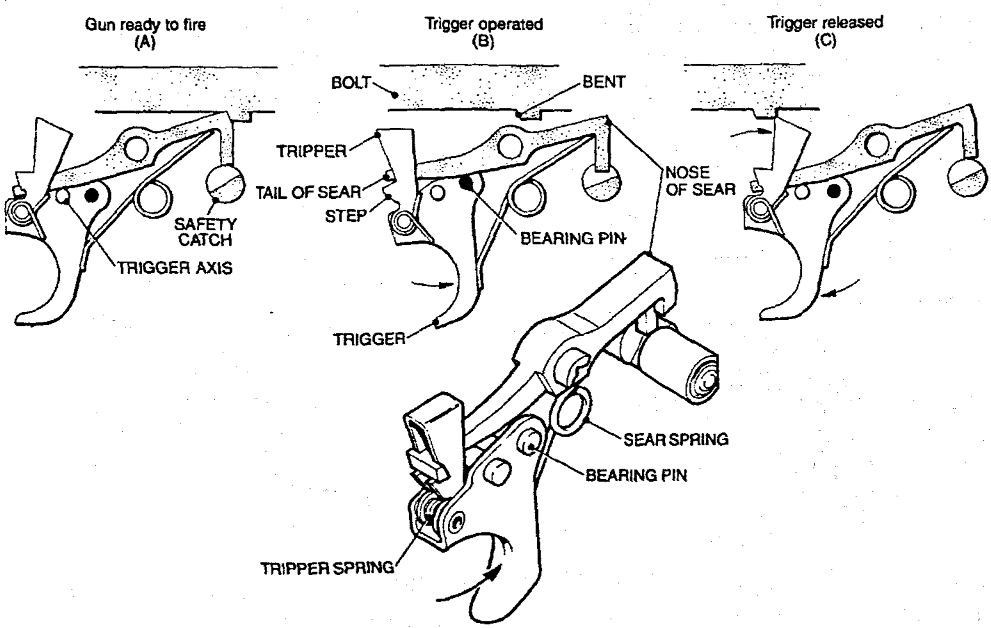


Fig 13.15 Controlled Sear, German MG3

The German MG42 first used this system. After WW2 the idea was largely copied by most other European designs including the FN MAG and subsequently the British L7A1 GPMG.

The arrangement of the sear is shown in Fig 13.15A. The trigger carries a tripper which is forced forward by its own spring. When the trigger is rotated, the tail of the sear goes up and the nose of the sear disengages from the bent of the bolt. The spring of the tripper drives it forward and a step rides under the tail of the sear. In Fig 13.15B, when the trigger is released, the tail of the sear can only fall a little way because it is held up by the step on the tripper, and the nose of the sear cannot rise. The rotation of the trigger pushes the tripper up into the path of the bolt that rides over it on the forward stroke but on the rearward stroke (having fired another round) drives the tripper backwards as in Fig 13.15C. This moves the step from under the tail of the sear, that then is free to fall and the nose of the sear rises into the bolt path. The bolt rides over the sear on its way back but the sear rises to present its full face to the bent on the next forward stroke.

The controlled sear has contributed significantly to the reliability of fast firing GPMG.

This system was introduced to solve one specific problem but it produces another. Since the tripper can only be rotated as the bolt comes back, the sear cannot rise until the bolt receives a rearward impulse and the weapon cannot be set to 'safe' until it is cocked. If however the working parts stop in the forward position, as with a misfire or an empty belt, the bolt has only to be pulled back an inch or so for the tripper to allow the sear to rise. The bolt can then be returned to the forward position and the change lever put to 'safe'. Any attempt to cock the weapon now jams the underside of the bolt against the unyielding sear that is locked up when the change lever is at safe. The bolt is then held by friction only and can go forward as soon as the spring force succeeds in overcoming the friction force, but the firer can well believe the bent has engaged the sear and the weapon is ready to fire. When the trigger is squeezed it will not move and the bolt will have to be forced forward to allow the safety catch to be pushed through the body to the 'fire' position. The gun can then be cocked.

It has also been found necessary in this type of weapon to put in a second bent, or, in the case of the British L7A2, a second sear, to ensure that, if the firer's hand slips whilst cocking the gun, a round is not accidentally discharged. Instead the bolt is held up until the cocking operation is continued and completed. This also guards against a runaway gun condition which can arise if, for any reason, the recoiling parts do not travel sufficiently to the rear to be held by the sear but far enough back to feed another round and fire it.

Applied Safety

The object of the applied safety is to prevent the unintentional discharge of the weapon. In single shot weapons it will operate when the weapon is in the 'ready' position with the action forward. In SL pistols it will again operate in the closed breech position, but with SMGs it may be required also to operate with the bolt forward or to the rear. SL rifles and automatic rifles require a safety catch to operate when the bolt is forward; all other automatic weapons need only to work when the bolt is in the 'ready' position.

Applied safety can function by:

- Locking the firing mechanism.
- Locking the sear.
- Locking the trigger.
- Disconnecting the trigger from the sear.

Of these methods, all of them in current use, locking the firing mechanism is the only one in which safety can be assured. In the others there is always the possibility of some part being jarred free if the weapon is grounded heavily or dropped. Some weapons incorporate more than one of these functions.

Locking the Firing Mechanism

The simplest example of all is the SMG where the bolt itself carries a fixed striker, usually on the front face of a large and heavy bolt. The usual procedure of locking the bolt is found in its simplest form in the later version of the STEN SMG where the cocking lever was used to lock the bolt in either the forward or rear positions.

Another example of locking the firing mechanism can be taken from the German P38 SL pistol, as shown in Fig 13.16. This pistol can be fired single action or double action. If the weapon is cocked and the change lever is then set to 'safe', the firing pin is positively locked and the hammer will go forward onto it.

The P38 pistol has another feature that assists the firer in preventing accidents. When there is a round in the chamber, a floating pin protrudes from the rear of the slide, above the hammer, as an indication of the loaded state. This pin can be seen by day or felt at night. The firer is thus never in doubt as to whether there is a cartridge in the chamber. This indication is used also in the Luger Pattern 08 SL pistol where the extractor is proud when the chamber is loaded. The American rifles, the Garand M1 and the M14 both employ the double bent system of producing SL fire. The applied safety, which can only be used when

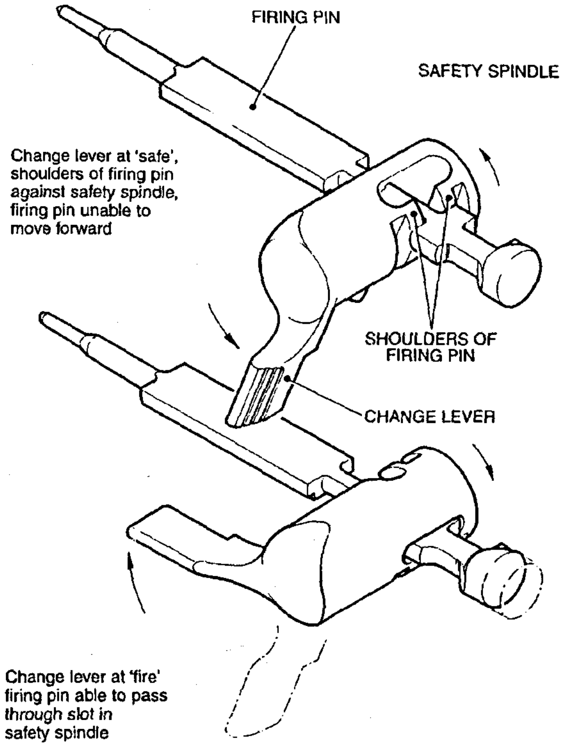


Fig 13.16 Locking the Firing Pin, P38 Pistol.

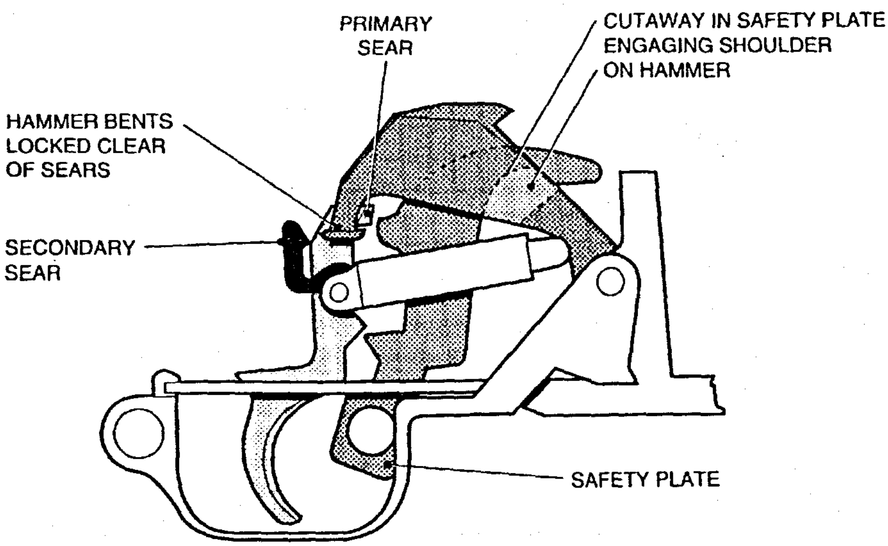


Fig 13.17 Locking the Firing Mechanism, USA M14 Rifle.

the hammer is cocked, is operated through the trigger guard. A plate is pulled back and at the top end this has a cut away which rides over a shoulder on the hammer, withdrawing the hammer from the sear and locking it securely. Thus part of the firing mechanism is locked as shown in Fig 13.17. It should be noted in this application that the firing pin itself is not locked.

Locking the Sear

This is the most common form of applied safety. In a typical SL pistol, such as the .45in Colt, putting the applied safety to 'safe' locks the sear lever so that it cannot operate to release the hammer. It is also common in an SL pistol for the safety to lock the slide, so that there is no possibility of the inertia of the slide causing it to move back whilst being carried and thus partially extracting the live round and causing a stoppage.

In the great majority of modern GPMGs the change lever spindle is of circular section with a 'D' cut out. The 'safe' position puts the full section under the sear which cannot then be depressed and so the gun cannot fire. When the 'fire' position is adopted the spindle is pushed across the body, or rotated according to the design, so that the cut out is positioned under the sear which then has room to move down to allow the weapon to fire. This system, as detailed in table 13.1 is extremely reliable and the possibility of breakage of the sear allowing the bent to go forward, is largely theoretical.

In some open breech firing weapons, the designer has allowed the firer to lock the sear with the bolt in the closed position. In the Russian RPD LMG the safety catch can be rotated to 'safe' when the bolt is fully forward. The sear is then locked rigidly in the up position. If the bolt is retracted, the bent cannot force the sear down to ride over it and the bolt jams. The bolt is thus held partly retracted and the contact between the bolt and sear prevents any movement of the change lever. In the field, of course, the cocking lever which moves back and forward with the bolt, can be hammered forward; but this action, undesirable in itself, can only be done if the firer appreciates the nature of his stoppage.

Locking the Trigger

This method is used in many weapons but it suffers from the disadvantage that failure or dislodgement of the sear will allow the weapon to fire. The British SMG, the L2A3, uses this method as detailed in table 13.1. The inner arm of the change lever bears against the tripping lever but exerts no turning moment so the sear is locked in the up position.

The FN FAL rifle and the British L1A1 use the system where the full diameter of the change lever spindle rests over the trigger lever that is unable to rotate when pressure is applied to the trigger. The way this operates can be seen in

the diagram of the trigger and firing mechanism of the L1A1 SLR shown earlier in this chapter.

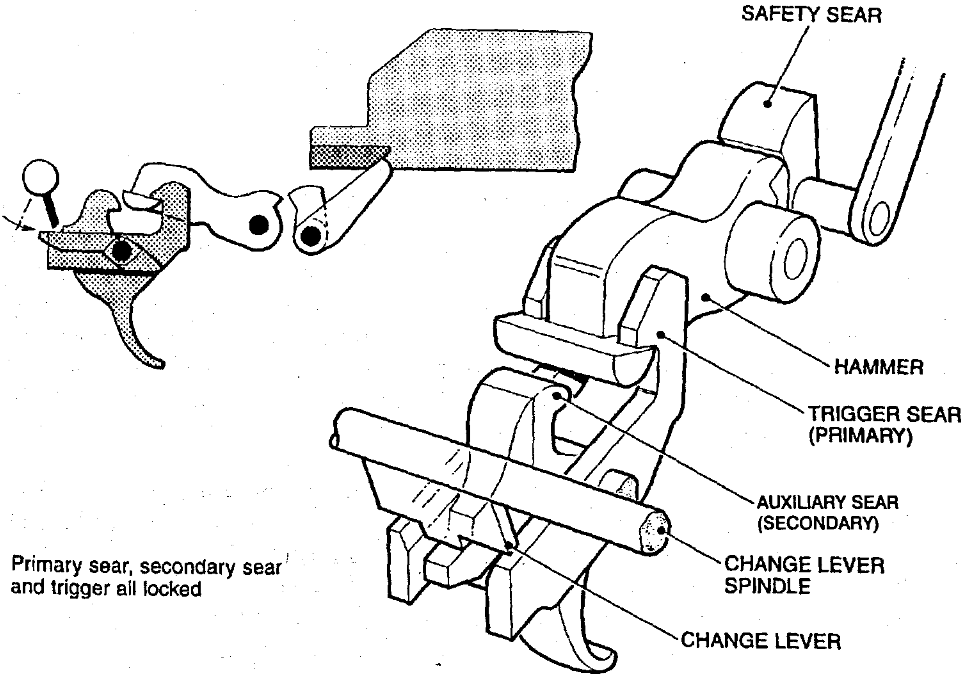


Fig 13.18 Applied Safety Trigger Locking, AK-47

The Russian Kalashnikov assault rifle family also uses this system. Fig 13.18 illustrates the operation. The change lever is a long bar lying along the right hand side of the body. When it is lifted to the safe position, the spindle rotates a massive lock over the trigger, that is prevented from rising to allow the main sear to release the primary bent on the hammer. At the same time the bar on the outside of the body prevents the withdrawal of the cocking handle. This prevents the underside of the bolt jamming against the hammer so that it cannot rotate when the safety is applied. The American Armalite AR15 and M16 family of weapons also use this method. Rotation of the change lever moves a bridge piece over the trigger preventing any movement.

Disconnecting the Sear from the Trigger

This system is used in a range of Czech designed LMGs including the BREN and the Vz 52. The diagram of the BREN trigger and firing mechanism, illustrated earlier, shows the use of the upper and lower surfaces of the window in the sear to produce single shots and automatic fire. If the change lever is set

to 'safe', the spindle forces the tripping lever into a midway position so that it engages neither the upper nor lower surface of the sear opening, but moves between engaging neither. Thus the trigger is disengaged completely from the sear.

This system is well tried and gives no trouble but, in theory at any rate, a heavy jar could always dislodge the spring loaded sear and allow the bent to go forward, discharging the weapon.

Electric Trigger and Firing Mechanisms and Circuits

Electric trigger mechanisms, when used in conjunction with mechanical firing mechanisms, are simply a remote control trigger device. The electric circuit conveys the operator's requirement for the gun to start or stop firing to the mechanical sear, which it will operate by some simple electric mechanism such as an electric coil and plunger. This system gives a very light mechanism for remote control apart from the source of electric power. It is simple to embody an applied safety in the trigger operating switch for the firer to control.

An electric trigger mechanism may be used in conjunction with electric firing mechanisms. They achieve the same effect as with mechanically operated firing mechanisms, except the firing mechanism itself is largely simplified since the ammunition actually contains the electric igniter device in its cap. All the electric firing mechanism has to embody is insulation and mechanical safety and to connnect the circuit to the round at the correct instant.

A complete electric trigger and firing mechanism will reduce 'lock time' to virtually zero if required, eliminating many complicated mechanical components, and is reliable if correctly designed. This complete system is very often used on aircraft, which carry their own source of electrical energy, and require the minimum possible weapon weights, which electric circuits provide in addition to simplicity of remote control.

Summary

Some applied and mechanical safety features for a few categories of weapons are set out in Table 13.1.

Table 13.1 Summary of Applied Mechanical Safety of Some British Land Service Weapons

Class	Name	Applied Safety	Mechanical Safety
Handgun	Revolver	Nil	Safety stop interposed between hammer and frame in uncocked position.
	9mm SL L9A1 Pistol	Safety catch: a. Locks sear with hammer cocked. b. Locks slide.	a. Sear is disconnected until locking is complete. b. Free movement of barrel and slide before unlocking starts.
SMG	9mm L2A3	Safety catch locks sear.	Cartridge cap and fixed striker are not in line until round is in correct position for firing.
Rifle	Rifles No. 4, No. 8 & L39A1	Safety catch: a. Locks striker. b. Prevents bolt unlocking. c. Withdraws and disconnects striker from sear.	Safety stud preventing operation of striker unless bolt is locked.
	Rifle 7.62mm L1A1	Safety catch locks trigger.	a. Hammer held until breech is locked. b. Free travel of breech block carrier before unlocking starts.
	Rifles 5.56mm AR & M16	Safety catch locks trigger.	a. Hammer held until breech is locked. b. Free travel of bolt carrier before unlocking starts.
Machine Guns	LMG L4 (BREN)	Safety catch disconnects trigger from sear.	a. Firing pin cannot be operated by piston post until breech is locked. b. Free travel of piston before unlocking starts.
	7.62mm L7A2 & derivatives.	Safety catch locks sear.	a. Striker cannot reach cap until locking is complete. b. Firing pin cannot protrude until locking is complete. c. Free travel of piston before unlocking starts.

14. Weapon Ancillaries

Scope

There are a number of items that complete the small arms weapon system. This book will not cover the design of bayonets, grenade projectors, blank firing attachments, silencers, moderators or flash hiders in any detail. However general points and some of the things that must be taken into account will be covered.

Muzzle or Barrel Attachments

There are two main types of muzzle attachment. The first category help the performance of the basic weapon, like a muzzle brake or flash hider. The second provide some extra role, such as a bayonet or grenade projector. The most common barrel attachments are:

- Muzzle brakes
- Recoil intensifiers
- Flash hiders
- Noise suppressors (silencers)
- Muzzle deflectors
- Blank firing attachments
- Grenade projectors
- Bayonets

Muzzle Brakes

Muzzle brakes decrease the recoil impulse on the barrel by directing propellant gases back towards the breech as they emerge from the barrel. This creates a negative impulse that reduces the overall recoil impulse acting on the barrel. The efficiency of a muzzle brake increases with the quantity of gases discharged from the muzzle and with their angle of deflection. Fig 14.1 shows a chamber muzzle brake with a system of side ports for venting the propellant gases. The efficiency of the chamber muzzle brake increases with the ratio of area of side ports to the area of the muzzle opening. Muzzle brakes can considerably reduce the recoil force acting on the weapon and so allow the weight of the weapon to be reduced. A perfect system would turn the gases through 180° symmetrically. This is obviously impossible. The computation of the effect of a muzzle brake is given in the chapter "Introduction to Methods of Operation". In practice the best one can hope to achieve is some 40% reduction in recoil. The first exit that the gases reach has the most effect and for each exit thereafter there is a diminishing return. Indeed there is little point in more

than three baffles. The main drawback to muzzle brakes is the rearward blast wave. This can stir up dust or cause the firer's position to be given away. At the same time a muzzle brake is a very poor flash hider. The better the brake, the greater the flash. For these reasons, snipers seldom use muzzle brakes, unless the recoil is uncomfortable, such as that from 12.7mm or 20mm anti-material rifles. There can also be a hazard to anyone beside the firer, such as his spotter.

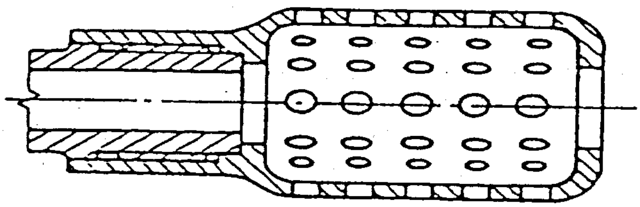


Fig 14.1 Typical Chamber Muzzle Brake.

Recoil Intensifiers

Recoil intensifiers have the opposite effect to muzzle brakes and are covered in the chapter on Recoil Operation.

Flash Hiders

The gases flowing out of the barrel are very hot. They contain carbon monoxide, hydrogen and methane, which combine with oxygen from the air as they emerge from the barrel. This may cause a flame to be formed at the muzzle creating a very visible weapon signature and even blind the firer for some time at night. Flash hiders reduce the temperature of expanding gases at the muzzle to below their ignition temperature. The early ones had a conical shape as shown in Fig 14.2, which also mechanically screened the flame from view. A greater effect is achieved by sucking cooling air through an opening in the rear part of the flash hider. Modern ones normally have between three and five prongs, either open or closed with a solid ring. There can be a small muzzle brake effect from a flash hider.

Noise Suppressors (Moderators and Silencers)

When a shot is fired it creates a loud noise. The sources of this noise are the propellant gases venting from the muzzle, the bullet passing through the air and the weapon mechanism moving backwards and forwards. The greatest component of this noise is caused by the shock wave from gases flowing from the barrel at supersonic velocity. The level of acoustic pressure of small arms noise ranges from 140 to 160 dB and exceeds the threshold of pain by 10 to 30 dB. Ear protection is therefore of the utmost importance when firing weapons. For special small arms, the noise level is reduced by means of a noise suppresser, the purpose of which is to reduce the velocity of the gases venting

from the muzzle. Gases that expand into the noise suppressor are cooled, their pressure reduced and their exit velocity lowered so that the noise caused by the venting gases is reduced. The noise suppressor is usually cylindrical with a large expansion volume in which temperature and pressure of the gases are reduced. A typical example of a noise suppressor is shown in Fig 14.3 and works very like a car silencer.

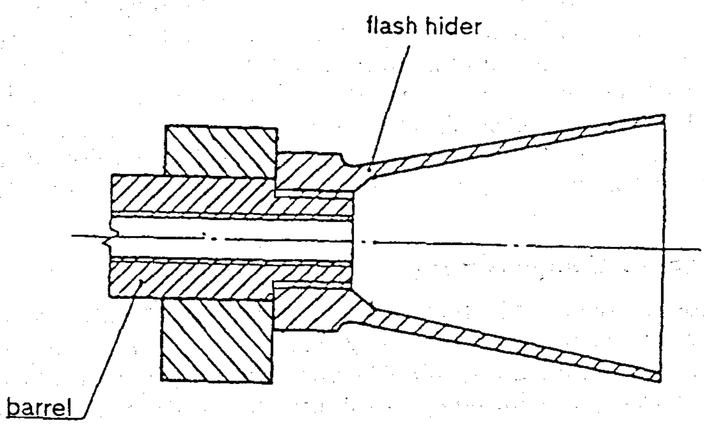


Fig 14.2 Typical Conical Flash Hider.

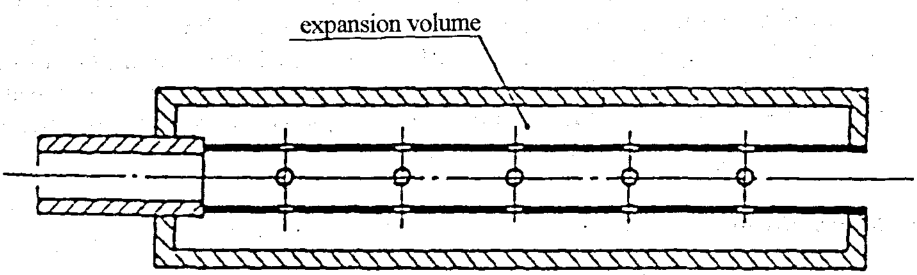


Fig 14.3 Construction of a Typical Noise Suppressor.

If the muzzle velocity of the bullet is greater than the velocity of sound, there will be a high-pitched crack from the shock wave created by the bullet. For maximum effect the bullet velocity is reduced to below the velocity of sound which will affect bullet performance and range, and may give weapon cycling problems if the weapon is designed to operate using full powered ammunition. Adding a silencer or moderator to a weapon makes it heavier and more unbalanced.

A moderator is added to the normal weapon, usually by screwing it onto the

end of the existing barrel. Unless the ammunition has been specifically down-loaded to cut the velocity of the bullet, it will exit at, or just above, its normal supersonic velocity. This will still make a supersonic crack as it passes down range and will have the same target effect as a bullet fired from a non-moderated gun.

Another, often neglected, source of noise is from the operating mechanism of the gun. A sub-machine gun firing from an open bolt can be heard up to 100m away when it is dry cycled. Because of this noise, modern silenced weapons tend to use special self-contained ammunition and can have more than one barrel. This special ammunition uses a piston to push the bullet out and seal the gases inside the cartridge case. A weapon that uses caseless ammunition could also make a very good silenced weapon because it does not need an ejection opening and the whole weapon could be covered with soundproofing.

Muzzle Deflectors or Compensators

A muzzle deflector is a device which counteracts the muzzle climb associated with automatic weapons firing bursts. They cause a reactive force on the muzzle which acts against muzzle climb. The reactive force is created by the deflection of the muzzle gases in the opposite direction to the required force. The construction of a deflector is quite simple. It is sufficient to machine a muzzle extension with an incline or to machine a number of vents beyond the muzzle on the upper surface of a muzzle extension. One of the most successful compensators in service is to be found on the AK74. This uses some extra holes in the top right quadrant of the muzzle brake and an offset baffle. One might think that such a compensator would be a good idea. However compensators are a form of muzzle brake with all the attendant drawbacks and, worse still, they only work for one person in one position. For these reasons no other country has adopted one on their service rifles.

Secondary Roles

Blank Firing Attachments (BFA)

For training there is an obvious need to fire blank ammunition. It is still necessary to function the weapon as if it were firing live rounds. Some method of blocking the barrel is needed in order that the weapon may use the gases as it would with its normal method of operation. This is normally achieved by attaching some form of choke to the muzzle, either full or partial, to retain enough pressure to operate the weapon parts. For a recoil operated weapon it is necessary to fit a special barrel with a much more powerful recoil intensifier to ensure the weapon cycles. There are two basic requirements for this attachment. Firstly it must not become dislodged whatever happens. Secondly it should ideally retain any ball round inadvertently fired, thus remaining safe for the firer and all others. This is a bigger problem than it might appear! Most

blank firing attachments cannot safely fire standard ball rounds so they are usually painted a bright colour so that the firer, and others who may be present when the weapon is fired, is aware that it is fitted.

Bayonets

These are dear to many infantrymen's hearts. The value of a bayonet on the end of a modern bullpup design is questionable. This is the reason that SA80 has a fighting knife with included sharpener, wire cutter and multi-purpose saw. Another requirement is that the barrel shall not just be ballistically strong, but also capable of withstanding the greater bending stress imposed upon it when bayonet fighting. It must also be remembered that a bayonet on the end of a rifle changes the zero of that weapon enough to guarantee a miss!

Grenade Projectors

Separate Launcher

The original weapon for launching high explosive (HE) grenades was similar to a rifle but of much greater calibre. The best known is the American M79 shown in Fig 14.4. The more sophisticated sights that were fitted were one of the advantages of such a weapon. The other advantage was that the barrel is rifled and this gives better accuracy than a fin-stabilised grenade.

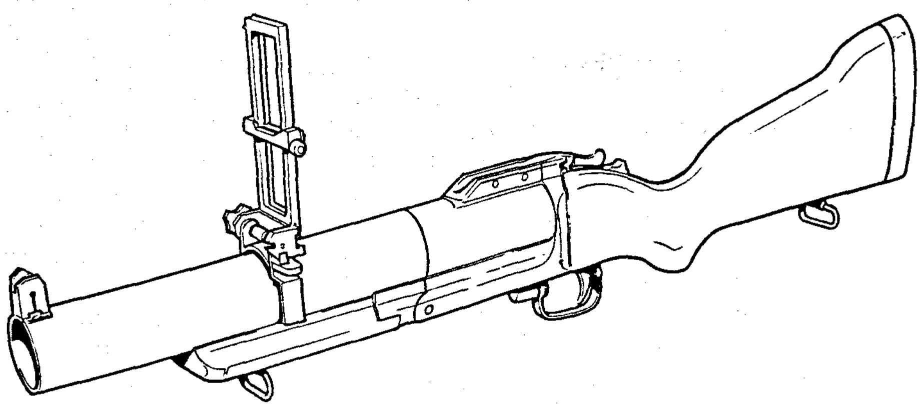


Fig 14.4 M79 40mm Grenade Launcher.

This entailed the carriage of two weapons. The Americans soon saw the need to integrate this HE projector with the rifle and the M203 was introduced on the M16 as shown in Fig 14.5.

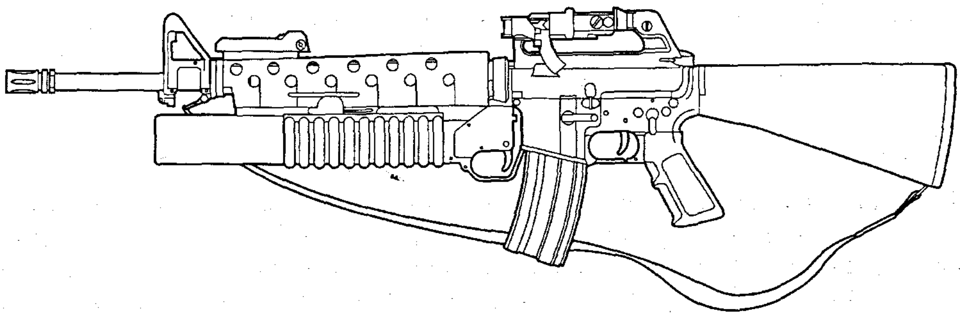


Fig 14.5 M16 with M203 40mm Launcher.

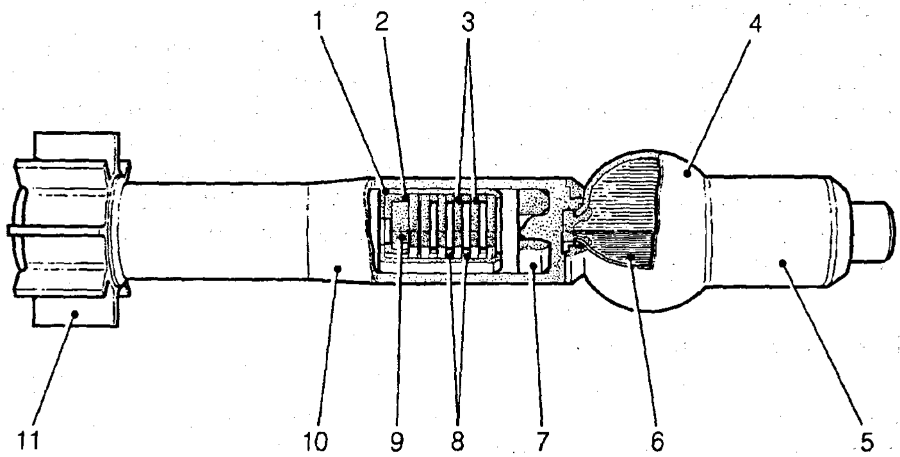
The problems are the accuracy with which the grenade can be projected. The mounting can become somewhat loose. The sights are rudimentary and the shock of firing not only builds an accumulated hurt on the firer's shoulder but also on the rifle. Not all rifles can take an M203. Indeed the USA were lucky that the M16/M203 combination appears to work fairly well. The attempts to fit the M203 to SA80 failed; although it must be said that SA80 was designed to take muzzle projected grenades. If it is desired that a weapon be capable of projecting a HE grenade, then it must be designed with that from the outset.

Muzzle Launched Grenades

Almost from the time of the musket, some form of grenade has been used. In the past the 36M hand grenade was projected from a cup-discharger using a ballistite cartridge. This entailed the replacement of the fuze for one of 7s and the addition of a round plate screwed to the base of the grenade. With the advent of the L2 grenade, an effort was made to fire this from the SLR from the same muzzle attachment as the Energa anti-tank grenade. This also required the loading of a special ballistite cartridge, which was not liked because it was too easy, in the heat of battle, to forget and fire a ball round with disastrous consequences. The recoil was also very great at around 145J that meant that it could not be fired from the shoulder. Firing from the ground meant that the energy had to be absorbed in the weapon for which it was not designed and consequently was easily damaged. Furthermore the method of holding the grenade's lever until the shock of firing released it was unreliable and the idea abandoned.

Bullet Trap Grenade

The more modern method of projecting a grenade from the muzzle of a rifle is to fire a round already to be found in the magazine of the rifle. Today this can be ball, tracer or even armour piercing. A trap in the stem of the grenade absorbs the bullet. The gases project the grenade. The bullet alone would only produce a range under 20m, whereas a maximum range of around 300m can be achieved. The layout of a typical bullet trap grenade is shown in Fig 14.6.



1	Trap assembly body	6	Explosive filling
2	Cup	7	Spacer
3	Steel, ceramic discs	8	Spacing rings
4	Grenade body	9	Rubber disc
5	Fuze assembly	10	Stabilising fins

Fig 14.6 A Typical Bullet Trap Grenade.

Bullet Through Grenade

Another way to launch a grenade from the muzzle of a rifle is to allow the bullet to pass through a self-sealing barrier, but use the gases as before. This may not be altogether acceptable in peacetime, but gives almost the same range. The design of such a grenade is shown in Fig 14.7. The main problem with this type of grenade is the design of a safety and arming and fuze mechanism with a hole through the middle.

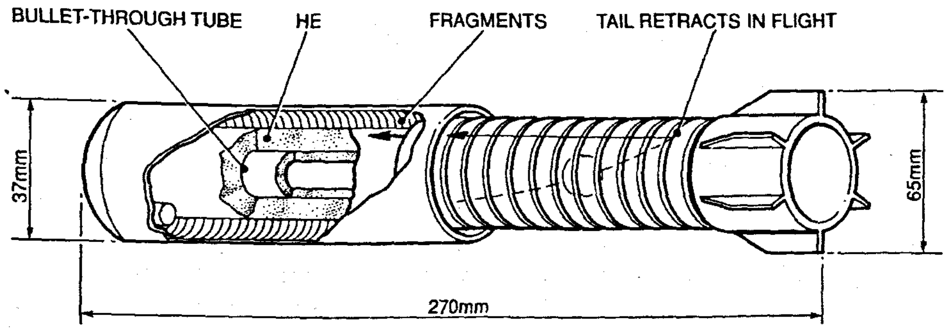


Fig 14.7 FN Telescopic Bullet Through Grenade.

General Problems with Projected Grenades

The main problems with these grenades are accuracy and lethality. Until recently, the sighting systems have been very poor. Add to this the inherent inaccuracy of the weapon, ammunition and firer, and the overall system accuracy is very poor. The recoil of any size of grenade is prohibitive and therefore projected grenades tend to be much smaller than the hand thrown variety. Indeed firing anything heavier than 500g from SA80 will give over 100J of recoil energy to be absorbed. This is painful to the shoulder and fired from the ground damages the weapon.

Theoretical Recoil Energy

When calculating the sort of recoil energy likely to be met, the contribution from the propellant mass need not be taken into account because of the overwhelming mass of the grenade.

15. Sights for Small Arms

Requirements

Every weapon system has some means of aligning the weapon with the target and this aiming system is usually referred to as the weapon sights. The basic purpose of the sighting system is to allow the weapon to be pointed at the target. It does this by directing the axis of the bore of the weapon so that the trajectory of the projectile crosses the line of sight to the target at the required range. Sighting systems are either direct or indirect.

Direct sighting systems are used on direct fire weapons and the line of sight is directed onto the target. It is necessary to make the appropriate target elevation correction for range and any deflection for wind or movement of the target.

Indirect sighting systems are used on mortars and guns and the actual target need not be visible from the weapon. Aim is directed onto an artificial aiming point, the angle of sight and tangent elevation for range being applied separately. An indirect sight is more complex because of the need for calculation and adjustment but is the most simple in actually taking aim because the aiming point is artificial; it can be made any shape or colour and can be illuminated at night. Also, the weapon is fixed and there is usually no great speed required in taking aim.

When most small arms are used, the target is fleeting and only briefly exposed. The weapon is not usually immediately positioned for use and must be brought onto aim. Thus the speed at which a target can be engaged will include the time taken to place the sights onto the target, to locate the target in the sight picture and to make the fine adjustments to correct the aim.

Accuracy of aim will vary considerably with the conditions under which the weapon is being used, and will depend on the type of target and lighting conditions. The conditions under which the weapon will most often be used is therefore of primary importance. However, sighting errors are only one factor in the overall accuracy of a weapon and ammunition. Increasing the accuracy of a sighting system usually results in increased cost and weight, so that it is important that the required accuracy of the sighting system is estimated to enable a realistic compromise to be made. The maximum field of view whilst aiming is important when viewing the target. Thus, a sight picture that will merge with the background is desirable with a minimum of a surrounding frame and minimum obscuration from graticules and sight protectors.

Eyesight

The degree of detail that the human eye can resolve given good eyesight, is in the region of one minute of angle. This falls off rapidly with poor lighting so that the finest elements in any sighting system should always be greater than one minute of angle at the eye. To adapt to different lighting conditions the eye varies the size of the pupil, being approximately 2 mm in bright light and expanding to a maximum of between 7mm and 8mm in poor light. Thus, for the maximum amount of light to be transmitted to the eye, the exit pupil or aperture of a sighting system should be 7 to 8mm diameter.

In bright light, with the pupil fully contracted, the depth of focus is at its greatest. It is, therefore, possible to obtain reasonable focus on a fore-sight in the region of 700mm from the eye and the target beyond. In poor light the pupil will dilate and the depth of focus become poor, so that either the fore-sight or the target will be out of focus. For very poor light conditions it is necessary for the eye to receive as much light as possible and it will not be possible to see the fore-sight. Under these conditions, it is necessary for all sight elements to be in one focal plane which is only possible with optical sights.

Open Sights

The simplest form of sight is that fitted to a shotgun and consists of a vertical blade or a circular bead attached to the top of the muzzle of the gun. There is no back-sight, correct alignment is achieved by ensuring that the eye of the firer is correctly and consistently positioned by the correct and consistent position of the stock of the gun relative to the eye. This type of sight is used where speed of engagement is more important than accuracy of aim. To improve accuracy a rear-sight is fitted, usually between 250mm and 400mm from the eye. The simplest rear-sight consists of a notch with which to align the fore-sight. With this system it is necessary to focus the eye on the rear-sight, the fore-sight and the target. This is not possible, so the eye is focused on each in turn in an attempt to achieve the correct sight picture placed on the target. This becomes more difficult with poor lighting conditions. Speed of aim is thus considerably reduced with this type of sight. Fig 15.1 shows a typical sight picture for open sights with a front blade and rear notch.

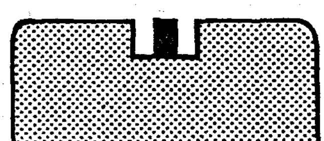


Fig 15.1. Typical Sight Picture for Open Sights with a Front Blade and Rear Notch.

Aperture Sights

Aperture sights use a small hole for the rear-sight, whilst retaining a vertical

post for the fore-sight. The fore-sight is viewed through the rear aperture, the eye automatically positioning the vertical post in the centre of the rear-sight. It is not necessary to focus on the rear-sight so the task of alignment of the front post with the target is simplified. However, target acquisition times are increased, compared with open sights, and for high levels of accuracy the rear aperture must be small. For target shooting in good light the rear aperture can be made as small as 1.3mm diameter. In bad light maximum light transmission is required and the rear aperture needs to be in the region of 7 to 8mm diameter. To overcome this problem, it is usual to fit the rear-sight with two selectable apertures, which for military use are usually in the region of 2.5mm and 7mm diameter. Fig 15.2 shows the typical sight picture for open sights with a front blade sight and rear aperture sight.

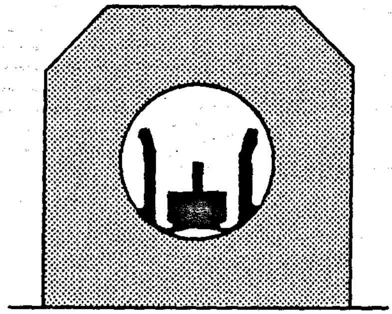


Fig 15.2. Typical Sight Picture for Open Sights with a Front Blade and Rear Aperture.

Optical Sights

Optical sights use some form of lens system. The simplest, and shortest, are collimator or lensatic sights. These are used to place the target image onto the same focal plane as the sight, as shown in Fig 15.3. A translucent graticule is positioned on the focal plane of the eye piece, which is a simple convergent lens. This lens is designed so that the light rays emerging from the graticule are parallel to each other and to the axis of the sight. Thus, it is only necessary to position the graticule onto the target. Both will be in focus because they are on the same focal plane. This type of sight has been used for many years for use with mortars. A triangular graticule is frequently used, the point of which is placed onto the target.

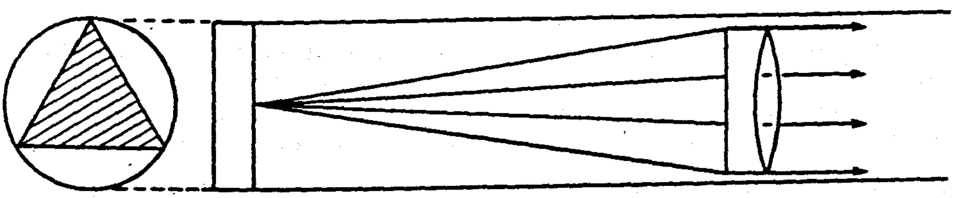


Fig 15.3 Simple Collimator Sight.

Rifle sights have also been developed based on this system, and are known as "singlepoint" sights. A light source is placed behind a pinhole in a diaphragm so that light is gathered by a convergent lens and made into a parallel beam of light as shown in Fig 15.4. This is projected into the eye of the firer as a spot of light. The sight is positioned on the muzzle of the weapon and, with both eyes open, the firer places the light spot onto the target. The light source is viewed with the right eye (if the right eye is the master eye) and the target is viewed with the left eye so the point of light appears to be positioned on the target. However, some firers have difficulty firing with both eyes open or whilst simultaneously viewing the light source and the target.

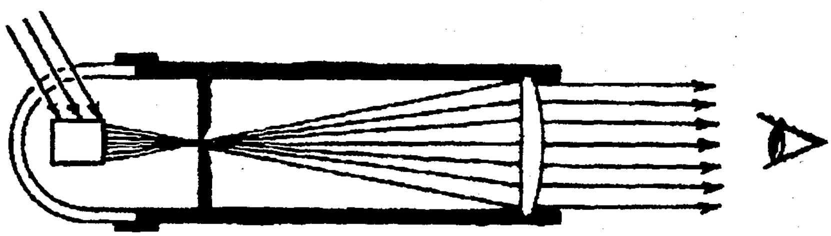


Fig 15.4. Single Point Sight.

Telescope Sights

The telescope sight is the most usual type of optical sight and is used for both military and sporting purposes. It offers magnification of the target but there are unity power telescope sights which still have primary advantages over iron sights. These advantages include a bright image and a single focused aiming mark. The magnification ranges from 1 to 24 power, but the higher magnifications suffer from limited field of view, warm air shimmer effects and accentuated weapon shake.

The accuracy of a weapon is not greatly improved by increasing the magnification of the sight so it is usual to use fairly low magnifications where possible to give a wide field of view. Additionally the sight can be used for surveillance purposes but this usually requires higher levels of magnification so the value selected is usually a compromise, depending on the scenario.

Unity to 4-power is the most common for assault rifles designed to engage targets out to 300 or 400m. Conventional sniper rifles use magnifications of 6 to 8 power and the long range anti-material large calibre rifles, used for engaging targets out to 2000m, have magnification from 10 to 16 power. For sporting purposes variable magnification telescope sights are popular but are not often used for military purposes because of their extra complexity.

The aiming mark is usually a simple graticule in the form of a fine cross for sniper type weapons although assault rifles may have a circle, which is used by

placing the target in its centre, or a vertical pointed post. Graduations on the graticule may be included to assist corrections for range, wind or target movement. The graticule may also have a facility to illuminate it for use in low light conditions.

Basic Telescope

Fig 15.5. shows a basic astronomical refractor telescope which uses an objective lens to produced an inverted image which is observed through an eyepiece. An aiming mark can be added at the focus of the telescope. Magnification is defined as the angular magnification resulting from the relative focal lengths of the objective lens and the eye piece and is given by:

$$\text{Magnification} = \theta'/\theta = f_o/f_e$$

An image of the objective lens is focused by the eyepiece onto the exit pupil, as shown in Fig 15.5, the rays of light entering the telescope passing through this minimum circle of the exit pupil. For maximum light transmission the eye must be placed at the exit pupil or the iris of the eye may act as a shutter. The position of the exit pupil can be found using a paper screen on which the objective lens is focused. The magnification of the telescope can also be fo 1 from:

$$\text{Magnification} = \frac{\text{Objective lens diameter}}{\text{Exit pupil diameter}}$$

The diameter of the iris of the eye can vary between 2mm in bright light conditions, to 8mm in dark conditions. Thus, to maximise visibility in poor light, the exit pupil should be in the region of 8mm and so the objective lens can be calculated for a given magnification, eg, for a x 4 magnification the objective lens should be approximately:

8mm x 4 = 32mm.

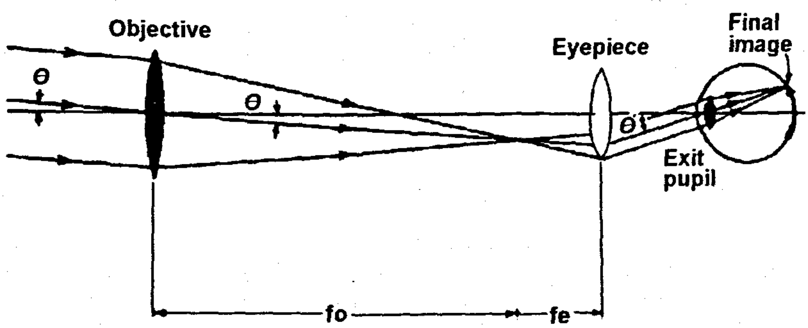


Fig 15.5 Astronomical Refractor Telescope.

To use a telescope as a weapon sight it is necessary to re-erect the invented image, which is achieved using an intermediate set of lens as shown in Fig 15.6. These lens are usually assembled in a cell which may be tipped vertically and horizontally by screws to adjust the point of aim of the sight graticule. These intermediate lens may also be fitted in an optical system to vary the magnification of the telescope for variable magnification sights.

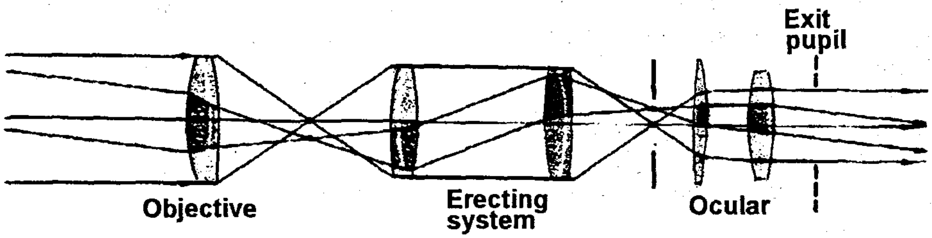


Fig 15.6. Intermediate Lens to Re-erect Inverted Image.

The distance from the eyepiece of the telescope to the exit pupil is called the eye relief. This distance must be sufficient, especially with large calibre weapons, to ensure that when the weapon recoils the eyepiece does not strike the eye of the firer. A soft rubber ring is often fitted to reduce injury if this does occur. To make allowance for different firers it is usual for the eyepiece to be designed so that it can be screwed backwards and forwards to adjust the focus of the reticule. There are ten or more lens surfaces in a telescope sight and reflective losses occur at each surface. Coatings are usually applied, known as blooming, to reduce these losses. Rather than using a set of lens to re-erect the image, a prism may be used. This has the advantage of reducing the length of the telescope. The optical sight fitted to the UK SA 80 assault rifle, known as the SUSAT, uses a prism re-erector system.

A problem with telescope sights are that they are focused onto objects which are relatively close to the telescope. If the image is not focused onto the reticule then any movement of the eye causes an apparent movement of the reticule, which is known as parallax. For low magnifications this effect is small, but for larger magnifications the effect has a significant effect on sight accuracy. It is, therefore, necessary to provide a means of adjusting the position of the objective lens to focus the image at the position of the reticule.

Reflex Sights

These are a simple optical sight with unity magnification. The aiming mark is illuminated by ambient light or by an electrical or tritium source. This is collimated by a lens and then reflected into the line of sight of the firer by a partially reflecting mirror. Fig 15.7 shows a simple reflex sight.

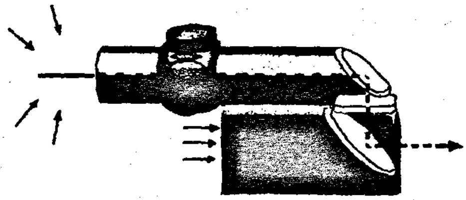


Fig 15.7. Simple Optical Reflex Sight.

Laser Dot Sights

These sights use a laser attached to the weapon to produce a bright spot of light which is pointed at the target, the position of the spot of light being zeroed to the mean point of impact of the weapon. This type of sight must be very bright to be able to see the spot of light in bright daylight; thus their power densities are such that they are usually not eye safe.

Bullet Trajectory and Zeroing

Almost all sights fitted to modern small arms are mounted on top of the weapon. Ignoring for a moment that the flight of a bullet is curved (see the section on small arms ammunition), when a weapon is zeroed it is necessary for the line of the sights to be coincident with the line of the bore of the weapon at the required range. However, there is the additional problem that the flight of a bullet is curved and this must also be taken into account. The coincident range of the sights and bullet is known as the zero range and is usually sufficiently distant from the weapon that the trajectory of the bullet is descending through the line of sight so that there is also a short range of coincidence. This range is referred to as the point blank range.

Fixed sights, as fitted to most short range weapons, usually have the facility to adjust the sights to enable the weapon to be zeroed at a fixed range. To engage targets at longer ranges than the zeroed range the firer must hold over an appropriate amount (i.e. fire above the target). Most long range weapons, such as rifles or machine guns, are fitted with sights that can be adjusted for use at different ranges. It is necessary for the firer to accurately judge the range of the target to make accurate use of the sight adjustment. For long range shooting, such as for sniper use and some vehicle mounted weapons, laser range finders are being increasingly used.

Initial approximate alignment of the sights can be achieved by bore sighting the weapon, providing it is possible to view the target through the bore of the gun. To bore sight a gun the weapon is held firmly and the target view directly through the barrel. Without moving the weapon the sights are then adjusted on to the target. This should be sufficiently accurate to correctly zero the weapon which should be carried out as follows:

- Fire a five round group at the target.
- Repeat four times, remounting the weapon between each group.
- Find the mean point of impact (MPI).
- Adjust the sights onto the MPI.
- Fire a five round confirmation group.
- Repeat the above if the group is not properly centred.

Zeroing can be carried out at short range, if necessary, using standard offsets to allow for the trajectory of the bullet. Whilst this is more convenient than long range zeroing it is less accurate.

An increasingly popular alternative to bore sighting and zeroing is the use of a sight alignment collimator. The stud of the collimator is inserted into the bore of the weapon at the muzzle and then the sights are adjusted onto the projected alignment grid. Fig 15.8 shows a typical sight alignment collimator. Whilst this method cannot give the weapon zero in absolute terms (it does not take into account the effect of gun jump for different weapons), it is sufficiently accurate for most purposes. An important use is to check the sight alignment after zeroing on the range and then use the collimator for checking the subsequent weapon zero.

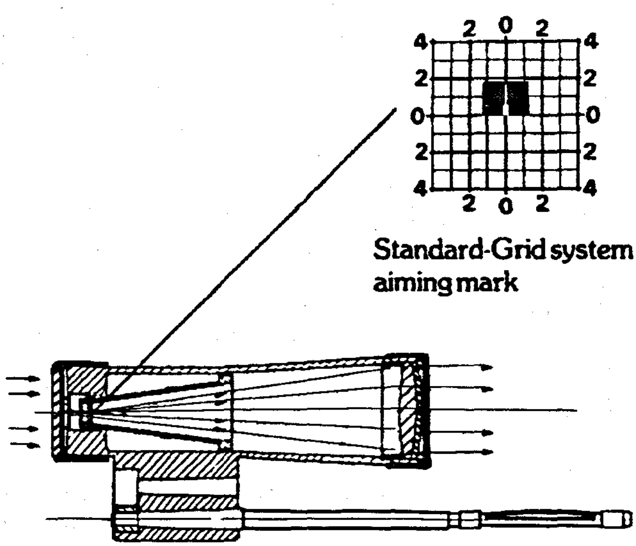


Fig 15.8. Sight Alignment Collimator used for Checking the Zero of Small Arms.

16. Dynamic Analysis of ✭ Operating Cycles

Purpose

The purpose of this section is to describe the approach used for analysing the movement of the working parts during the operating cycle of a conventional self powered automatic weapon. The operating cycle is divided into two phases: the first phase is the rearward movement of the working parts and the second phase is the return movement of the working parts to their original working position. The motive power for driving the automatic cycle is derived from the propellant gases each time the weapon fires. The amount of energy used is in the region of 1% of the muzzle energy of the weapon and so therefore has an insignificant effect on weapon performance.

The energy from the propellant gases only acts for a very short period of time. During this short period kinetic energy is imparted to the working parts and they are accelerated rearwards. At the end of this short period, the working parts have reached their maximum velocity and have maximum kinetic energy. It is this kinetic energy which is used to overcome the different forces resisting the motion of the working parts. Additionally, it is necessary to return the working parts to their forward position. The energy to do this comes from the energy stored in the return spring which originated as the kinetic energy of the breech block.

There are two basic equations of motion for the working parts of a self powered weapon: one for the rearward movement and the other for the return or forward movement. These equations will differ in detail for the different types of operating cycle but the form of the equations will be the same. The following will describe the approach used for the blow back operating system and then look at the modifications necessary for gas and recoil operated weapons. The approach used for externally powered weapons will then be explained. It should be stressed that only the basic approach to analysing the operating cycles of different weapons will be covered here. A full mathematical solution is presented in *Brassey's Essential Guide to Military Small Arms* (see Bibliography).

Blow Back Operation

Fig 16.1 shows the schematic arrangement of a typical blow back operated weapon and the forces acting during its operation.

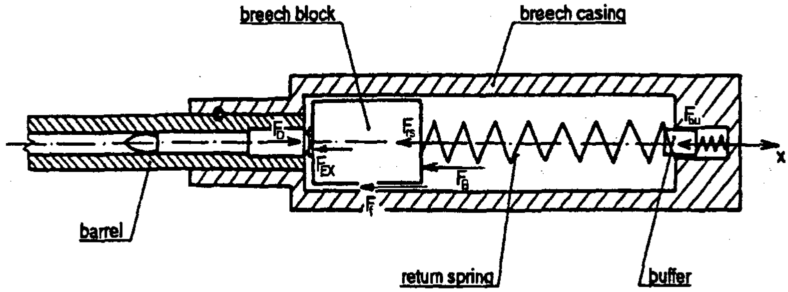


Fig 16.1 Schematic of a Typical Blow Back Operated Weapon

The equations of motion of the breech block of an automatic weapon for a simple blow back operated gun are:

- Rearward movement:

$$m_{bb}\frac{d^2x}{dt^2} = F_D - F_{rs} - F_{EX} - F_{bu} - F_B - F_f - F_{HS} \ldots \quad (1)$$

- Forward movement:

$$m_{bb}\frac{d^2x}{dt^2} = F_{rs} + F_{bu} - F_m - F_f \ldots (2)$$

where m'_{bb} = reciprocating mass
x = displacement of the reciprocating parts
t = time
F_D = force acting on the inner cartridge case diameter
F_{rs} = return spring force
F_{EX} = cartridge case ejection force
F_{bu} = buffer spring force
F_B = braking force
F_f = friction force
F_{HS} = force to cock firing mechanism
F_m = force to remove a round from the magazine

These equations equate the forces acting at different positions in the operating cycle.

Reciprocating Mass, m'_{bb}

On the right side of the equations are the forces acting on the reciprocating breech block at different points in the operating cycle. On the left side of the equations are the effects of these forces in terms of breech block acceleration and the reciprocating mass. From the acceleration, the breech block velocity and displacement at different points in the operating cycle can be calculated. However, the reciprocating mass is not fixed, it will vary through out the operating cycle and this will affect the breech block acceleration.

The reciprocating mass, m'_{bb}, varies according to breech block displacement, x. The initial reciprocating mass will consist of the breech block and the mass of the cartridge case. In addition, there will be a contribution from the return spring mass. This contribution is usually taken as one third of the return spring mass because although most of the return spring will be moving the velocity and acceleration will vary along its length. It has been found that these variations can be taken into account by only taking one third of the return spring mass.

When the cartridge case has cleared the cartridge chamber it will be ejected from the weapon. Thus the mass of the reciprocating parts will be reduced by the mass of the cartridge case.

During the rearward motion of the breech block it cocks the firing mechanism ready to fire the next shot. As it does so it comes into contact with the hammer and so the moving mass is increased by the amount of the hammer. Once the hammer is cocked the reciprocating mass will be reduced by the amount of the hammer mass.

Finally, when the breech block reaches the rear of the weapon it hits the buffer. Thus the breech block mass is increased by the amount of the buffer mass plus one third the mass of the buffer spring.

During the initial forward movement of the breech block, the total moving mass is that of the breech block, plus one third the mass of the return spring. During this forward movement a fresh round is fed into the path of the breech block for feeding into the cartridge chamber. Thus the mass of the forward moving parts is increased by the mass of the unfired round.

Rearward Driving Force, F_D

The driving force for the whole of the operating cycle is the force acting on the base of the cartridge case by the high pressure propellant gases. This driving force, F_D, is calculated from the chamber pressure multiplied by the area of the base of the cartridge case. This driving force acts for only a very short period but is very large due to the high propellant pressure, thus the acceleration of the breech block is high. Sufficient kinetic energy is imparted to the breech block to drive it to the rear of the weapon against the various forces that are acting on it.

Forces Opposing Rearward Movement

Extraction Force, F_{EX}

When a round is fired the pressure in the cartridge case is sufficiently high to plastically deform it. Thus there will be a residual hoop stress in the cartridge

case causing it to grip the walls of the cartridge chamber. Additionally, the high pressure will also force the cartridge case against the wall of the cartridge chamber. The force to extract the cartridge case will depend on the surface contact area, coefficient of friction between case and chamber, as well as the material properties and dimensions of the cartridge case. As the case is extracted the contact area will diminish, thus the extraction force will diminish until it reaches zero, at which time extraction will be complete. For a tapered cartridge case it is only necessary to extract it sufficiently to clear the taper for the extraction force to be zero.

Return Spring Force, F_{rs}

It is usual for the return spring to be preloaded. The initial force to begin compressing the return spring will therefore be the preload value. As the breech block moves rearwards the return spring will be compressed and the force required to compress it will increase. This increase will depend on the spring stiffness and the breech block displacement.

Friction Force, F_f

Friction always acts to oppose motion. In a simple blow back system there will be a friction force between the breech block and the guide ways in the receiver of the weapon. This friction force will be considerably increased if the resultant force acting on the breech block does not act through its centre of gravity. If the resultant force is off set to the centre of gravity there will be a turning moment which will increase the friction force. The greater the offset then the greater will be the friction force. Additionally, it is usual to over cock the firing mechanism with the breech block carrier which results in a force acting at right angles to the breech block carrier which pushes it into greater contact with the slides, thus increasing the friction force.

Braking Force, F_B

For a pure blow back operating system there will be no braking force. For delayed blow back systems there will be a breaking force applied to the breech block to slow its movement so that the time the cartridge case is supported will be increased. This allows the use of a lighter breech block or a higher chamber pressure.

Force to Cock the Hammer Spring, F_{hs}

As the breech block moves to the rear of the weapon it is necessary to recock the firing mechanism so that it will be ready to fire the next shot. The firing mechanism is usually spring driven and the breech will need to apply the force necessary to compress the firing mechanism spring.

Breech Block Buffer Force, F_{bu}

Small calibre blow back weapons are not usually fitted with a buffer system but rely on the breech block impacting the rear of the weapon casing. Larger calibre weapons are usually fitted with a buffer system because the magnitude of the impact is sufficient to damage the weapon. However, whatever the system that is used, there will be a force opposing the motion of the breech block when it reaches the rear of the weapon casing. For a proper buffer the initial force will be the value of the preload on the buffer spring. As the spring is compressed the force will increase in proportion to the displacement of the spring and will also be dependent on the spring stiffness. For a weapon without a buffer system the rear of the casing will act as a very stiff spring with very little displacement. There will however, be no preload force.

Forward Driving Force

With the breech block in the rearmost position it is necessary to return it to the fully forward position ready for the next shot to be fired. The energy to do this comes from the energy stored in the compressed breech block spring and buffer spring. The driving force can be calculated from the springs' characteristics and the springs' displacements (the amount they are compressed by). All springs have energy losses associated with them because of friction. Buffer springs are usually designed to have high frictional losses to dissipate the kinetic energy of the rearward moving breech block. Friction always opposes motion so that the spring stiffness will always be higher when it is being compressed than when it is expanding, the exact value of the spring constant being dependent on the spring efficiency. The losses are taken into account by increasing the value of the spring stifness in compression and reducing it in extension.

Forces Opposing Forward Movement

Friction Force, F_f

Friction opposes motion in whatever direction it is moving. The friction force opposing the forward movement of the breech block will be affected by the same factors as the friction force opposing the movement in the rearward direction.

Cartridge Feed Force, F_m

As the breech block moves forward a round is moved in front of it which must then be removed from the magazine or cartridge belt. There will be a friction force that must be overcome by the forward moving breech block and these will depend on the areas of the contact surfaces and the forces between them.

Solution of the Equations of Motion

It is necessary to use a numerical method of integration to solve the equations of motion because there is no simple mathematical expression for the different variables. An example of this is the driving force, F_D, which varies with respect to time. This force is dependent on the pressure in the cartridge case; whilst the pressure/time curve can be calculated using a variety of different internal ballistic models the results obtained are not in a suitable form for mathematical manipulation. For accurate results, and results which give a high degree of confidence, it is usual to measure the pressure/time curve and this can only be dealt with in a subsequent mathematical analysis using numerical methods. Most of the other forces, especially frictional forces, are obtained from empirical methods.

It can be seen from the above that it is necessary to divide the operating cycle into small parts where the reciprocating mass is constant, or can be assumed to be so, and to solve each part separately and add the results from each to the next part of the cycle.

Gas Operated Weapons

It is possible to use the same approach to analyse gas operated weapons as has previously been undertaken for blow back operated weapons. The driving force acting on the breech block however, will result from the propellant gases acting on a piston, the propellant gases being fed from a port drilled in the barrel of the weapon; (if the pressure in the cartridge case is still high when unlocking occurs there may be a significant force acting on the base of the cartridge case which must also be taken into account in the analysis). Fig 16.2 shows a typical arrangement of a gas cylinder used for the analysis of gas flow through the gas ports.

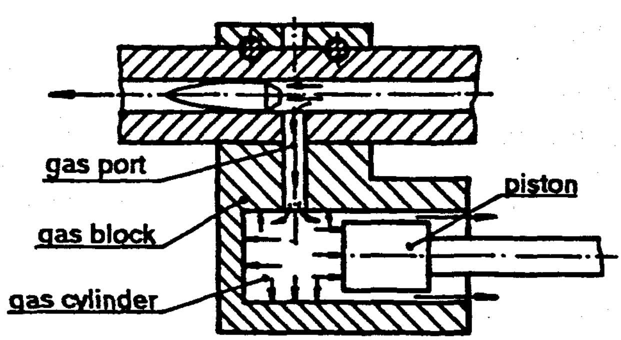


Fig 16.2. Schematic for the Analysis of Gas Flow through the Gas Ports.

The force acting on the gas piston is calculated from the gas pressure and the piston area. The main problem in obtaining a solution to the equation of motion is the determination of the pressure in the gas cylinder with respect to time.

The whole process can be analysed as gas flowing through a channel connecting two vessels of varying volume. In the first vessel, the barrel, the pressure rises steeply to a typical pressure approaching 200MPa. This then falls due to the movement of the bullet. In the second vessel, the gas cylinder, the piston moves due to the gas pressure acting on it, thus increasing the gas cylinder volume. Additionally there will be a reduction in gas pressure due to leakage past the piston and cylinder walls.

The process begins with the bullet passing the gas port and gas flowing through it to the gas cylinder. The initial gas velocity will be critical (the velocity will be greater than the speed of sound in the gas). Pressure in the gas cylinder will increase and a point will be reached where the gas cylinder pressure and barrel pressure are equal. After this the pressure in the barrel falls below the pressure in the gas cylinder and the flow will reverse. Fig 16.3 shows a typical pressure/time curve for the barrel and the gas cylinder.

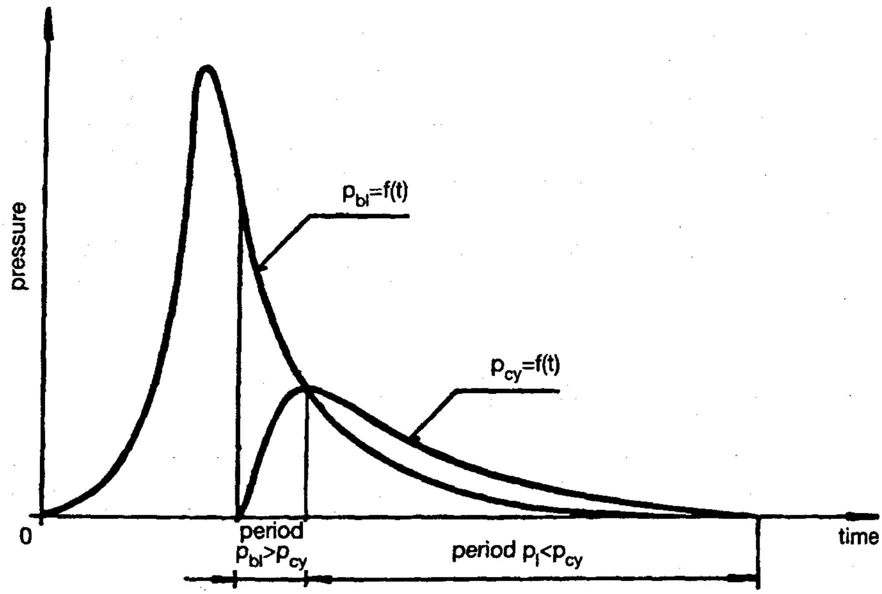


Fig 16.3. Typical Pressure/Time Curves for Barrel and Gas Cylinder.

The gas laws are used to calculate the flow rates and therefore the pressures in the cylinder and the barrel from which the force acting on the piston, and hence the breech block, can be calculated. It must be remembered that, when calculating the acceleration of the breech block, the additional mass of the piston assembly must be taken into account and any piston return spring.

Each design of piston assembly is different but it is common to vent the gas cylinder pressure to atmosphere after a short displacement of the piston. Subsequent to this the driving force from the piston will be zero.

Long Recoil Operated Weapons

In long recoil operated weapons the barrel is attached to the breech block during the rearward movement of the working parts. Additionally, there is a recuperator which is used for returning the barrel to its forward position, the return spring being used for returning the breech block. Thus when the barrel and breech block recoil to the rear of the weapon housing the recoiling mass consists of:

- Barrel mass, m_b
- Breech block mass, m_{bb}
- Mass of the cartridge case, m_{cc}
- One third the mass of the recuperator, m_{re}
- One third the mass of the return spring, m_{rs}

In addition to the forces acting on the breech block of a blow back weapon, as given in equation (1) on page 258, there will also be the force required to compress the recuperator. Note also that the cartridge case extraction and ejection take place during counter recoil.

During the forward movement of the barrel the breech block is held to the rear and so the forward moving mass will consist of:

- Barrel mass, m_b
- One third the mass of the recuperator, m_{re}

Finally there will be the feeding of the next cartridge and the closing of the breech. Fig 16.4 illustrates the operating cycle for a long recoil weapon.

Short Recoil Operated Weapons

Short recoil weapons use a variable transmission ratio system between the barrel and the breech block. It is usually in the form of a lever accelerator whose mass is small compared to the barrel and so can be ignored in the analysis. Fig 16.5 shows the typical functional diagram for a short recoil operating system.

The phase for the rearward moving barrel and breech mechanism is divided into four separate periods for the development of the equations of motion.

First Period of Motion

The barrel and all recoiling parts are locked together and move towards the

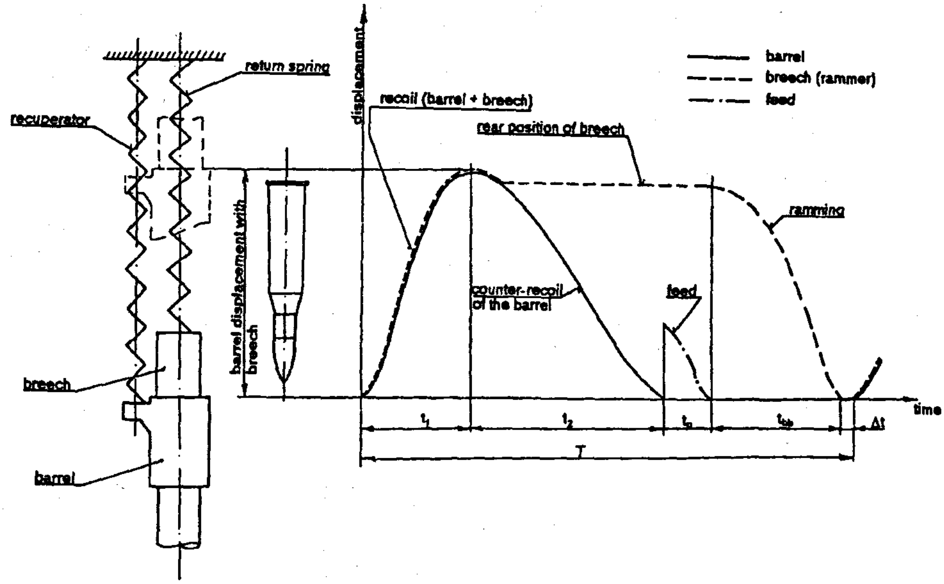


Fig 16.4. Functional Cycle for a Long Recoil Operated Weapon.

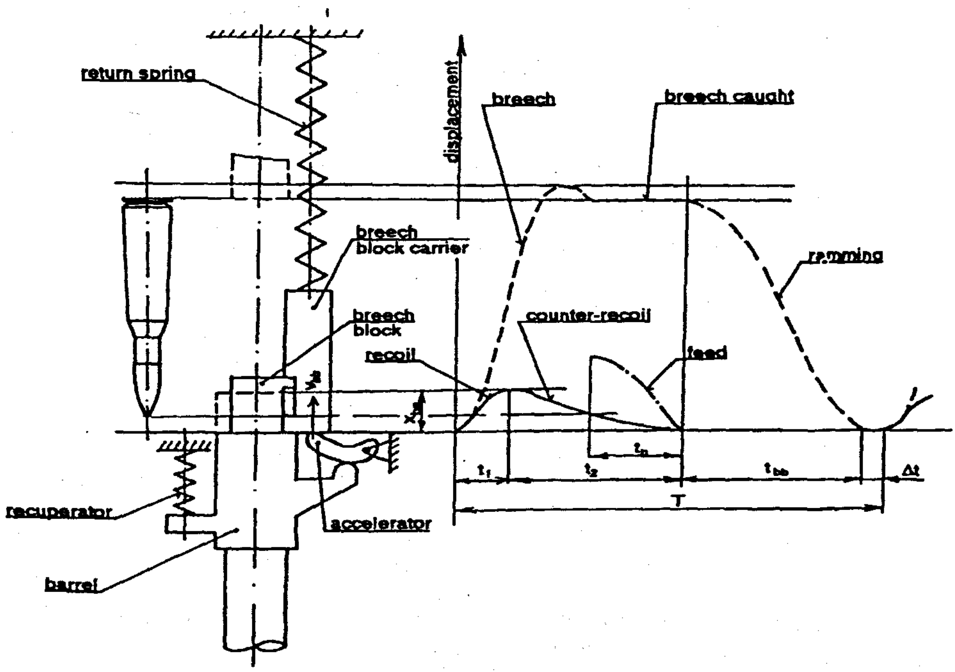


Fig 16.5. Typical Functional Diagram for a Short Recoil Operating System.

rear of the weapon in exactly the same manner as a long recoil operated weapon. Thus the first period of motion is analysed in exactly the same manner as that of the long recoil weapon, except the force of the buffer is omitted because the first period ends before the buffer is reached.

Second Period of Motion

This is the period during which there is breech block underslide, so that there is relative movement between the barrel and the breech block carrier which is achieved by the accelerator. However, because of the underslide the breech remains locked to the barrel. Fig 16.6 shows the action of the accelerator lever between the barrel and the breech block carrier.

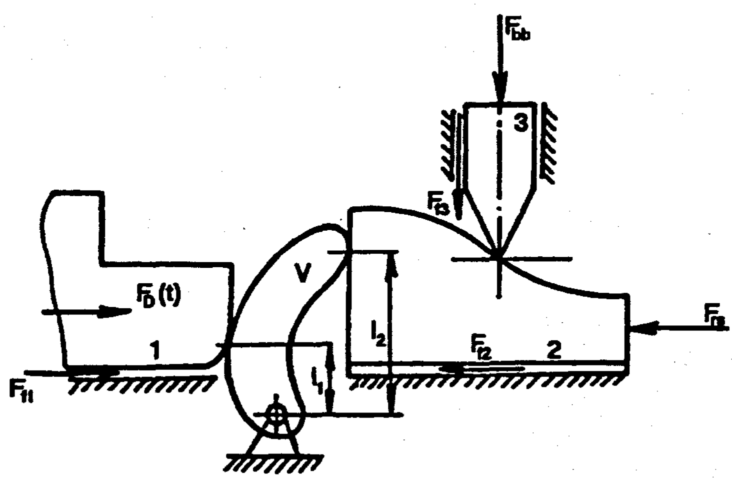


Fig 16.6. Accelerator Lever for a Short Recoil Operated Weapon.

Equivalent mass of the recoiling parts is given by:

$$m_b = M_A + \frac{i^2}{\eta} M_B \quad \text{.................................(3)}$$

where

$$M_A = m_b + m_{bb} + \frac{1}{3} m_{re} \quad \text{.............................(4)}$$

$$M_B = m_{bc} + \frac{1}{3} m_{rs} \quad \text{.............................(5)}$$

I = transmission (leverage) ratio of accelerator lever
η = mechanical efficiency
m_{bc} = mass of breech block carrier

Third Period of Motion

During this period the breech unlocks. The accelerator acts on the breech block carrier which controls the movement of the breech block through a cam system as shown in Fig 16.4. The force applied to the cam system is calculated in the same manner from the mass of the breech block and its acceleration. The breech block acceleration will be dependent on the cam profile. Additionally, there is the residue propellant pressure acting on the internal base of the cartridge case, which may be as high as 10-20MPa when the breech unlocks. Equations (4) and (5) are used for calculating the equivalent mass of the reciprocating parts.

Fourth Period of Motion

This period lasts from breech unlocking to the end of the accelerator action. The breech block and carrier are driven to the rear of the weapon and the cartridge case is extracted from the chamber. The equation of motion, including efficiency and transmission ratio, is similar to that of the second period.

At the end of the fourth period the remainder of the operating cycle is similar to that of the blow back system.

Externally Powered Weapons

A noticeable difference between externally powered weapons and self powered weapons is that the power is available for driving the weapon parts throughout the whole operating cycle. Thus it is not necessary to store kinetic energy in the breech block for the rearward movement of the working parts and it is not necessary to have a return spring to store energy for the forward movement of the working parts. Typical externally powered weapons are the chain gun series of weapons, the functional diagram of which is shown in Fig 16.7.

The analysis of this type of mechanism is carried out from a different perspective than self powered weapons. A major reason for carrying out a design study is to identify minimum power requirements, whereas with a self powered weapon it is to manage the energy which is available in such a manner that the weapon will function under all conditions.

Newton's second law of motion is used to balance the forces, masses and accelerations. However, the analysis is usually less complex than for a self powered weapon because of the fewer components involved. In addition to the absence of a return spring, there is no buffer or buffer spring. It can be seen from Fig 16.7 that much of the movement of the working parts is at a constant velocity, which means zero acceleration. Also, those accelerations that do occur are usually progressive and controllable.

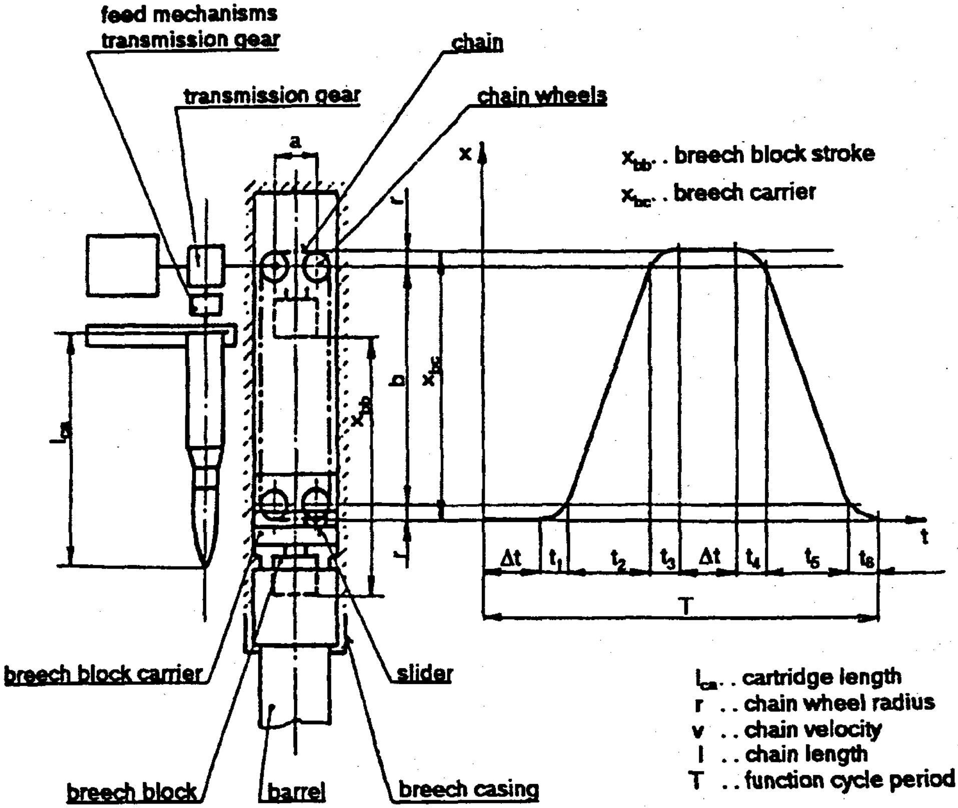


Fig 16.7. Functional Diagram for the Chain Gun Series of Weapons.

17. The Future

While the basic requirements set out below change very little with time, the hardware solutions change with the technological advances.

Small arms technology development for the last 200 years has been one of evolution rather than revolution. It is expected that in the foreseeable future, and certainly for the next replacement phase for small arms, this trend is likely to continue. Thus the small arms of the foreseeable future are likely to be developments of current technology rather than revolutionary concepts, such as directed energy technology. In its paper 'Infantry small arms (post 2000) AC/225 (panel III) D/296', NATO has set out what it sees as the future threat to the infantry and the future infantry requirements. The NATO definition of small arms is:

"Portable Direct Fire Individual or Crew Served Weapons Used Primarily for Anti-Personnel Operation."

Almost all infantry weapons of today (less mortars and anti-tank weapons) come within this definition. It is expected that the primary role of the infantryman in combat operations will continue to be:

- Close with and destroy the enemy.
- Hold or capture ground.
- Separate elements of the enemy so that they can be destroyed in detail.

The tactical functions of small arms are, and will continue to be:

- Close assault
- Protection of other weapons
- Suppression to allow movement and enhance application of heavy fire power
- Secondary function: defence against light vehicles (light armoured and unarmoured) and aircraft.

To perform these roles and functions the tactical capabilities of small arms must include:

- Decisive, violent target effects.
- Accuracy: all weather, day/night, fleeting and defilade targets.
- Low volume of fire with increased lethality.
- Lightweight (weapon and ammunition).
- Affordability, simplicity and ruggedness.

The need for acquiring these capabilities demands technological advances that provide:

- Desired target effect (MUNITIONS).
- Accuracy of range estimation under combat conditions (FIRE CONTROL).
- Enhanced armament to launch the munition (ARMAMENT).

Future Technological Approach

Munitions Technological Avenues

NATO has taken historical data from WWI, WWII and the Korean war which shows that 60% of casualties were caused by explosive fragmenting munitions to propose that this may be the way forward for small arms development to produce the required improved performance in small arms. It is suggested that the approach that should be used is:

- Small, lightweight, explosive, fragment – producing projectiles capable of defeating personnel targets whilst not requiring a direct hit (lethal radius) and able to defeat point targets such as light armour and helicopters.
- Multi-projectile technology that increase hit probability.
- Improved terminal ballistics for the lowest logistic burden.
- Multi-function tuneable projectiles to defeat specific targets.
- Special purpose projectiles (smoke, pyrophoric, chemical, anti-optic).

- Propellant improvements (higher energy, caseless ammunition, liquid propellants)

Fire Control Technical Avenues

- Combination day/night sights.
- Electro-optical sights for single point aim.
- Small, lightweight range finders.
- Thermal image devices.
- Single aim point/adjusted aim point.

Armament Technological Avenues

- Lighter, more durable weapons using modern materials.
- Weapons designed for ease of use and maintenance.
- Reduced audible and visual signature.
- Multi-function with common modular construction to reduce number of different weapons and fire control systems in a unit.
- Burst/salvo capability.

The Weapons Family

The aim is to deliver decisive and accurate fire power with increased lethality using lightweight weapons and ammunition with increased effective range. A family of weapons has been proposed that will meet the above requirements. The desired characteristics of these weapons are:

- Personal Defence Weapon

Munition	-Deadly at 50m -Lightweight -Easily stowed
Fire Control	-90% Ph at 50m -50% Ph at 100m

Armament -0.7kg
-Hands free carry
-Acquire/fire quickly

- Individual Combat Weapon

Munition -High PI at 300m (500m desirable)
-High suppression at 600m (1000m desirable)
-Gunner acquisition assistance
-Bursting and KE
-Non-lethal training aid

Fire Control -90% Ph Point target at 300m
-50% Ph to 600m (area)
-Rapid acquisition and engagement
-Eliminate range estimation
-Adjusted point of aim
-Gunner acquisition assistance
-Modular
-Embedded training

Armament -4.5kg
-Proliferable
-Easy to carry
-Low signature
-Embedded training
-Bursting and/or KE

- Support Weapon

Munition -Bursting
-High Pi and suppression at 1000m (2000m desirable)
-Family of ammunition

Fire Control -High Pi and suppression at 1000m (2000m desirable)
-Eliminate range estimation
-Adjusted point of aim
-Gunner acquisition assistance
-Modular
-Embedded training
-Day/night capable
-Rapid acquisition and engagement

Armament -Lightweight
-Proliferable
-Sustainable

-Low signature
-Embedded training

The targets for the above weapons are assumed to be protected by the titanium/kevlar body armour, details of which are given in the CRISAT Technology Area 1: Target Definition document. As well as personal protection, the CRISAT document has standardised the armour protection for which future weapons will be required to defeat for light trucks and helicopters. This same document gives the size of the target as well as the levels of protection.

With the levels of protection and target sizes standardised, and from the predicted weapon performance of future systems, it is possible to conduct lethality studies for these conditions. These studies indicate that the desirable features of the different weapons set out above are difficult to achieve. It should be noted that the above requirements do not give the levels of exposure of the target (target size), movement and duration, the environmental conditions (day or night or weather conditions) or the number of engagements, or the times between engagements. For most studies on these future weapons it has been assumed that the target is fully exposed, there is no limit on exposure times and engagements take place in daylight and in good weather. It is also assumed that the weapon weights are for an empty weapon.

Studies on the Personal Defence Weapon show that achieving the desirable levels incapacitation at the required range from such a light weapon will be very difficult to achieve. Hand gun ammunition will not provide the lethality at the required ranges against the specified levels of protection. There is a trend in the development of small calibre high velocity rounds for this type of weapon as typified by the FN 5.7mm calibre x 28mm round which achieves a muzzle velocity in the region of 700m/s with a bullet weight of 2grams when fired from a 150mm long barrel. Recoil impulse is less than half that of the 9mm calibre x 19mm round which it, or some derivative of it, is set to replace in the future. However, that only overcomes one part of the problem, that of providing sufficient penetration to defeat the target. The other two problems are the weight limit and the problem of hitting the target. These conflicting requirements are tending towards the development of two weapons, one of sub-machine gun configuration, using a butt for better control and giving the accuracy at the required range and the other of pistol configuration.

For the Individual Combat Weapon and the Support Weapon there is a move in the direction of fragmenting munitions to achieve the hit probability and lethality requirements. Current developments in future Individual Combat Weapons appears to be for a combined weapon that has similar capabilities to current assault rifles and with a high velocity semi-automatic grenade launcher of about 20mm that fires a fragmenting round. It is planned that this fragmenting round will have an electronic fuse that will be able to provide an air burst facility against troops and point detonation against vehicles.

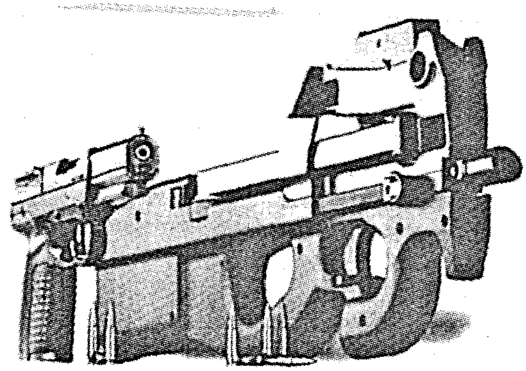


Fig 17.1 Fabrique National P90/SS190 (5.7 x 28mm) & P57 Pistol *(courtesy of FM Herstal S. A.)*

Fig 17.2 AAI's Objective Individual Combat Weapon *(courtesy of AA1 Defence Systems)*

Current developments in future Support Weapons appears to be towards an automatic weapon with a rate of fire of approximately 300rpm and firing a 25mm calibre high velocity grenade. Again it is planned that the fragmenting round will have an electronic fuse that will be able to provide an air burst facility against troops and point detonation against vehicles.

Any form of fragmenting round to fulfil the above requirements in 20 or 25mm will lack space for an effective warhead, be complex and expensive. The cost

effectiveness of such rounds is yet to be proven.

High velocity rounds of large calibre and weight will cause recoil problems so that it will be necessary to provide recoil management systems. However, the required weapon weight for true crew portability would make the fitting of such devices a difficult thing to achieve. There will also be the logistical problems of ammunition supply for ammunition of such bulk and weight.

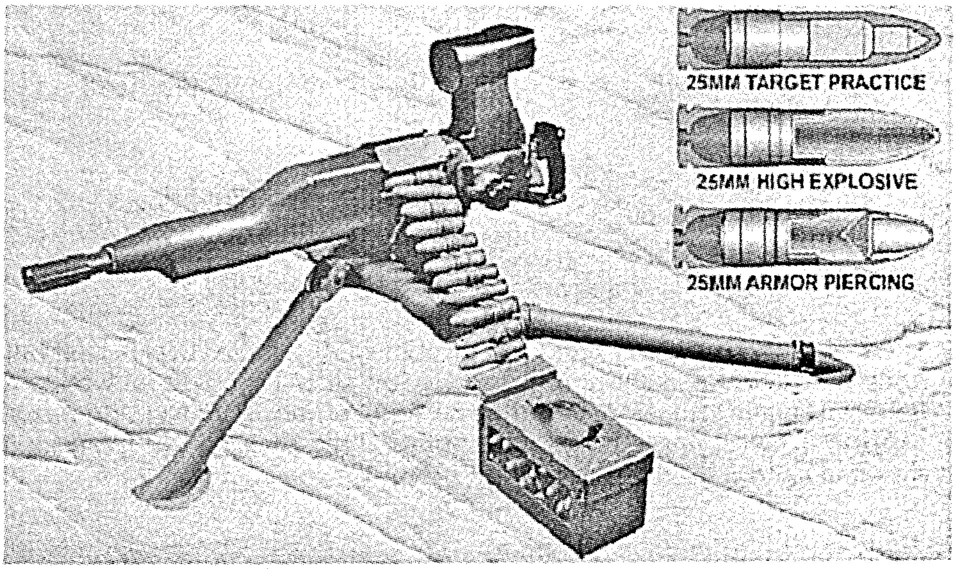


Fig 17.3 Olin's Objective Crew Served Weapon *(courtesy of OLIN Ordnance)*

There is a perceived need to increase the effectiveness of small arms in terms of the ability to hit and incapacitate a protected target at the required combat ranges. Current weapons are able to achieve many of the future requirements but when they are put in the hands of troops under combat conditions it is very difficult to achieve the performance of which the weapon is capable.

Fragmenting rounds with their electronic fuzes, once perfected, may well increase suppressive effects and increase hit probability. However, troops are only suppressed if the weapons they are confronting prove to have a level of lethality that causes them to be afraid of being badly hurt. Fragmenting rounds are unlikely to increase the lethality of infantry weapons because personal and vehicle protection has been developed to protect against fragments from artillery, mortars and grenades at certain distances from the explosion. These current fragmenting munitions are substantially larger than the munitions likely to be developed to fire from small arms so they are likely to be less lethal. Not all of the target is protected and it may be that studies will show that high hit probabilities against non-lethal areas will bring about the necessary overall weapon requirement, but this requires a large number of fragments.

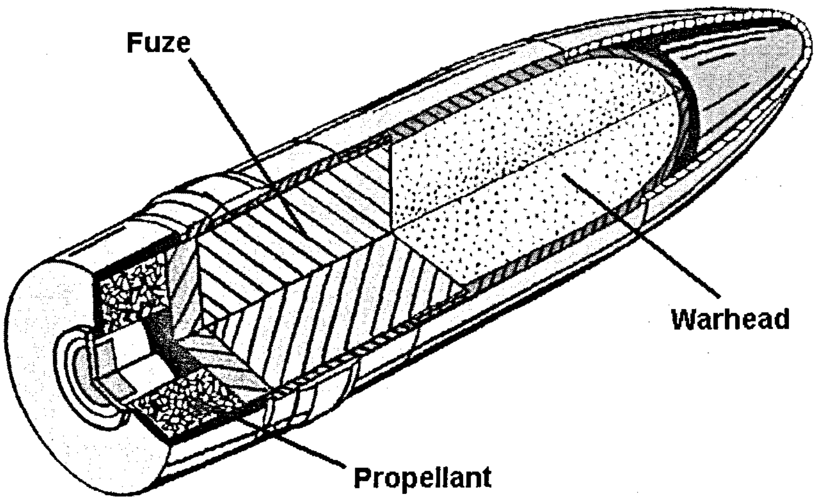


Fig 17.4 A Typical 20mm HE Round

There are other specialist areas not mentioned in the NATO paper on Small Arms post 2000. A number of countries feel that the list should contain a combat shotgun, sniper rifle and some form of longer range, anti-material weapon, if not a longer range sniper rifle. Three such typical weapons are shown in figures 17.5 to 17.7.

Fig 17.5 Neostead 13 Round 12Bore Pump Action Shotgun *(courtesy of Neostead)*

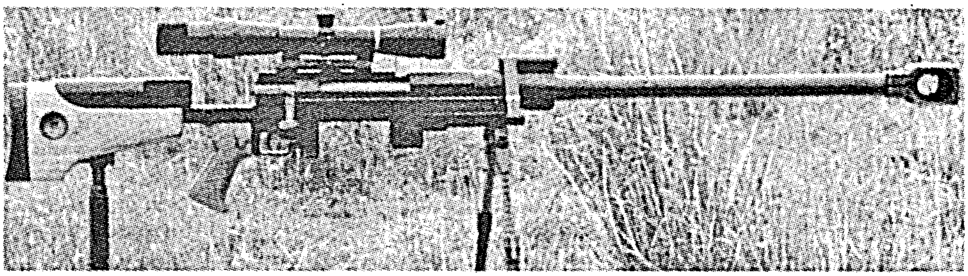


Fig 17.6 French HECATE II 12.7 x 99mm Sniper/Anti-material Rifle *(courtesy of CAFS Course RMCS)*

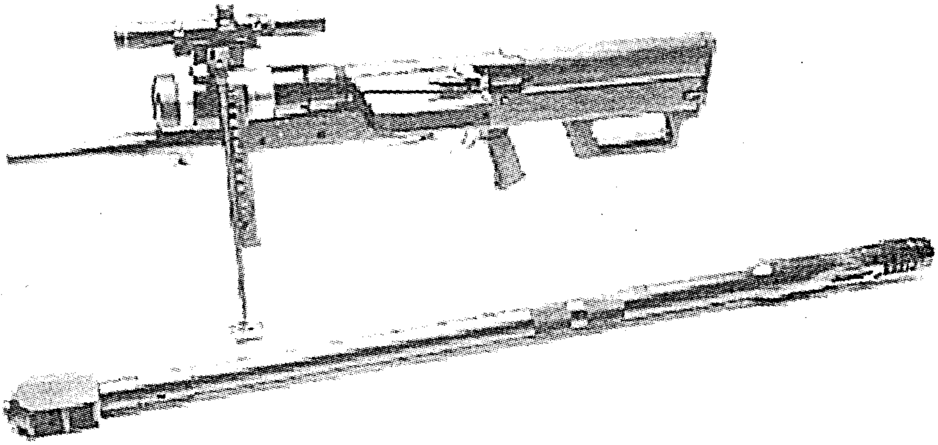


Fig 17.7 South African 20mm Anti-material Rifle *(courtesy of Aerotek)*

Glossary

A

Absolute temperature
: Temperature scale where absolute zero is –273°C, used in calculating barrel heating.

Action
: The mechanism of a firearm whereby it is loaded, fired and unloaded.

APC
: Armoured Personnel Carrier.

AP
: Armour Piercing.

Aperture sight
: A rear metal sight with a small circular hole through which the target and the foresight are centred when aiming.

Assault rifle
: A small arm that uses a rifle type round, but is smaller and lighter than a rifle, but larger than an SMG.

Automatic
: The firing of a succession of rounds until the trigger is released or the ammunition runs out.

B

Ball powder
: A nitro-cellulose propellant that, when manufactured, forms small balls. It produces less peak chamber pressure than cut tubular propellant, but a greater pressure at the muzzle.

Ball round
: A jacketed bullet normally lead cored, but may contain some other metal parts.

Ballistic coefficient
: A number indicating the efficiency of a bullet in overcoming air resistance.

Ballistite

A term applied to a smokeless propellant used mainly to propel a warhead from the end of a weapon. It is more powerful than a blank and tends to burn for longer.

Barrel time

The time taken for a bullet to travel from the instant it starts to move to the moment it leaves the muzzle.

Beaten zone

An area on the ground into which a succession of bullets fired from a weapon will fall.

Bent

A recess, normally in the breech block, into which the sear fits. When engaged the breech block is prevented from moving, normally forwards.

Bipod

A two-legged support placed under a weapon to support its weight in order to allow more accurate shooting.

Blank

A cartridge or shell, without a projectile, intended to produce a noise when fired. The propellant is normally of a fast-burning variety to compensate for lack of bullet resistance.

Boat tail

The tapered shape of the rear of a bullet normally used on rounds for longer range shooting.

Bolt

The component that holds and supports the base of the round while it is being chambered, fired or extracted.

Bore

The hole running down the length of the barrel through which the bullet is projected.

Breech block

Normally this component houses the bolt, adds mass to the recoiling parts and provides the bent recess.

C

Calibre

The nominal internal diameter of the bore, measured from land to land, or the nominal diameter of the projectile.

Cam

A rotating or sliding piece that has a contoured surface or projection that bears upon another piece in order to impart a special, rotating or eccentric movement.

Cannelure

A circumferential groove in a bullet normally used to hold it in the cartridge case after crimping

Cap

The portion of the base of the round that contains the primer compound.

Carbine

This is usually a rifle that has been cut down both in length of barrel and weight in order to make it easier to carry.

Cartridge

The complete assembly of primer, case, propellant and bullet that goes to make a round of ammunition.

Caseless ammunition

Ammunition that has no outer material to contain, or protect the propellant, or provide rearward obturation.

Centre-fire

Where the primer is located in the centre of the base of the cartridge case.

Chamber

The part of the barrel into which the cartridge is loaded and fired.

Charge mass

The amount of propellant contained in the cartridge case.

Closed bolt

Weapons firing from a closed bolt have a round in the chamber before the trigger is pressed.

Cocking

The process of making a weapon ready to fire, normally by moving the working parts.

Compensator

A form of muzzle brake where some of the propellant gases following the bullet are diverted to mitigate the upward jump of the muzzle on firing, especially in automatic or burst firing.

Cook off

The unintentional firing of a round due to the propellant becoming hot enough to cause spontaneous combustion.

Counter-recoil

The forward motion of the gun or the working parts after having moved backwards due to recoil.

Crimp

The inward bend or lip used to hold the bullet firmly in the case.

Cyclic rate

The number of rounds that a weapon will fire in one minute given a continuous supply of ammunition.

Cylinder

The rotating part of a revolver mechanism that houses the chambers holding the rounds.

D

Danger space

Either the space in which the trajectory of a bullet does not rise above the average height of the target, or, the space around the bursting point of an exploding shell dangerous to the target.

Detonation

A violent explosion as opposed to a deflagration or low order burning of a propellant

Disconnector

A feature in the trigger mechanism of a automatic weapon to prevent the gun being fired unless the action is fully closed and to prevent the firing of more than one shot for each pull of the trigger.

Double action
: The type of firing action where pulling the trigger not only cocks but also fires the weapon.

E

Ejection
: The expelling of the empty case or unused round from the weapon.

Emissivity
: The measure of an object's ability to radiate or absorb heat.

Energy density
: The muzzle energy of a bullet divided by the cross-sectional area. An indication of the penetration potential of a round.

Erosion
: The wearing away of the bore by gas action.

Extraction
: The withdrawal of an empty case or unfired round from the chamber.

F

Falling block
: Where the breech block moves vertically up and down

Field of view
: The area visible when viewed through an optical sight. The higher the magnification, the smaller the field of view for a given size of instrument.

Figure of Merit (FOM)
: A measure of the dispersion of a batch of ammunition. The smaller the better.

Firing pin
: The part of the firing mechanism of the gun that strikes the primer and causes the propellant to ignite.

Flash hider
: A muzzle attachment that hides or eliminates the flame that exits the muzzle.

Flash hole
: The hole in the primer through which the flame from the primer passes to ignite the main propellant charge.

Furniture
: The parts of a weapon that go to make it comfortable to hold and carry.

G

General Purpose Machine Gun (GPMG)
: An automatic weapon capable of both the section or light role, as well as the medium or sustained fire role, with modification.

Group
: An area into which a number of rounds, normally five or more, aimed at the same point, arrive.

H

Hammer
: A piece that delivers a blow to a firing pin

Hand gun
: A pistol, revolver or other weapon capable of being fired when held in one or both hands.

Hangfire
: A greater delay than is expected between the striking of the cap and the ignition of the propellant.

Headspace
: A distance between the face of the breech and the point where the cartridge bears.

Heavy Machine Gun (HMG)
: An automatic weapon of 12.7mm calibre, up to 20mm, that can be broken down and carried by a crew.

High explosive (HE)
: A chemical substance that will detonate.

I

Ignition time

The time that elapses between the firing pin striking the primer and the bullet starting to move.

Impulse

The product of a force multiplied by the time that force acts on a object. Measured in Newton seconds (Ns)

Individual weapon (IW)

An assault or plain rifle, seldom required to engage a target beyond 600m.

Inertia

That property of a body that dictates that it shall remain at rest or in uniform motion in a straight line unless acted upon by some external force. A body with high inertia will be hard to move or stop.

J

Jacket

A casing that forms the outer covering of a bullet.

Jam

A term for a stoppage caused by an object becoming jammed or causing a foul of the working parts.

Joule (J)

The unit of Energy measured in Newton metres (Nm).

Jump

The movement of the muzzle of a weapon due to the reaction of the firer to the weapon's recoil.

K

Keyhole

The elongated hole made in a target by a yawing bullet due to insufficient spin.

Kinetic energy (KE)

The energy of a moving object.

L

Lands

The raised portion or ridges between the grooves in a rifled bore.

Lead

The gap between the front of the chamber and the commencement of the rifling.

Light Machine Gun (LMG)

An automatic weapon, normally with a bipod, changeable barrel, portable by one man, firing from an open bolt, capable of more sustained fire than a rifle, out to the range required by a section (600m).

Light Support Weapon (LSW)

Normally a rifle with a longer and sometimes heavier barrel, fitted with a bipod for the same tasks as a LMG, but with a less need for sustained fire.

Line of fire

An imaginary straight line continuing down the axis of the bore when the weapon is fired.

Line of sight

An imaginary straight line from the weapon sight to the target.

Lock time

The time between the release of the sear and the detonation of the cap.

Lot number (Ammunition)

A code number that identifies a particular quantity of ammunition when it is manufactured.

M

Machine gun

A firearm capable of automatic fire.

Machine Pistol

Normally a pistol with some form of butt or other holding device, allowing targets to be engaged at slightly longer range.

Magnum

A term implying a cartridge giving higher than normal velocity.

Mean Point of Impact (MPI)
The centre of a group of shots.

Medium Machine Gun (MMG)
An automatic weapon, normally fired from some form of mounting, crew served, not as portable as a LMG, belt fed and with good sustained fire capacity and a greater useful range, perhaps even out to 2000m.

Medium Support Weapon (MSW)
Similar to a MMG.

Misfire
A failure of a round to fire properly or completely.

Momentum
A measure possessed by a moving body, mathematically expressed by mass x velocity.

Muzzle brake
An attachment secured to the muzzle of a gun and using the propellant gases to cut down the recoil.

Muzzle energy
The kinetic energy of a round on exit from the muzzle.

N

Neck
That portion of a bottle-necked cartridge case reduced in diameter into which the bullet fits.

Newton
The unit of force (kilogram metre per second^2)

O

Obturation
The sealing at the breech end of the barrel in order to prevent any escape of high pressure gas.

Open bolt
Weapons firing from an open bolt or breech, have the working parts held to the rear before firing, thus ensuring that no round is in the chamber until the trigger is pressed.

P

Primary extraction

The small but powerful initial rearward movement of the empty case in order to unseat it from the chamber.

Primer

An easily initiated explosive to be found in the cap of a cartridge.

R

Rate of fire

The practical number of rounds that can be fired from a given weapon.

Rate of twist

The distance moved down the barrel for the bullet to make one complete revolution.

Receiver

The metal part of the gun that houses the breech and firing mechanisms, sometimes called the frame.

Recoil

The rearward movement of the gun due to its discharge.

Recoil Energy

Normally calculated or measured as free recoil energy.

Revolver

A repeating handgun having a number of chambers in a rotating cylinder that are indexed around by the action of pulling the trigger.

Rifle

A long barrelled weapon, fired from the shoulder, used for accurate shooting to 600m or more

Rifling

The spiral grooves in the bore of a barrel used to spin the bullet and keep it stable in flight.

Rim

The part of a round of ammunition that allows the extraction of that round from a chamber.

S

SA

Abbreviation for Small Arm or Single Action.

Sear

A catch in the firing mechanism of a gun that engages in a bent in the breech block or restrains the firing pin, thus inhibits firing until the trigger is pulled.

Self loading

A firearm that automatically extracts, ejects and reloads another cartridge ready for firing. Also known as auto loading.

Semi automatic

The same as self loading but likely to be single shot.

SF

Abbreviation for Sustained Fire.

Shoulder

The tapered portion of a cartridge case, between the body of the case and the neck holding the bullet.

Single action

Normally in a revolver, where the weapon must be manually cocked before it can be fired.

SLR

Self Loading Rifle.

Small arm

Generally a weapon that is manportable, fires a flat trajectory projectile of 12.7mm or less.

Sub-Machine Gun (SMG)

This is also a term seldom used today, having been replaced by PDW, but covering an area between a Hand Gun and a Rifle.

T

Terminal velocity

The velocity of the bullet when it ends its trajectory.

Time of flight

The elapsed time from leaving the muzzle to the end of its trajectory.

Trajectory

The usually parabolic path of a projectile through the air.

Trigger

The part of the firing mechanism pulled or squeezed that releases the hammer or firing pin.

V

VMMG

Vehicle Mounted Machine Gun.

Y

Yaw

The angle between the tangent to the trajectory and the longitudinal axis of the projectile at its centre of gravity.

Z

Zeroing

The adjustment of the sights so as to move the MPI of a group to the correct position in relation to the point of aim.

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